

Merced River Salmon Habitat Enhancement Project Phase III - Robinson Reach

Engineering Report

**A Joint Project between the California Department of Water Resources
and the California Department of Fish and Game in cooperation with:
the Delta Pumping Plant Fish Protection Agreement (Four-Pumps), CALFED
Bay Delta Program, U.S. Fish and Wildlife Service, CVPIA-AFRP, Tracy
Fish Mitigation Agreement, Bureau of Reclamation, the Integrated Storage
Investigations Fish Passage Improvement Program, and Robinson Cattle Co.**



**California Department of Water Resources
San Joaquin District
River Management Section**

June 1, 2001

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Robinson Reach (Phase III) Engineering Report

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Bureau of Reclamation
Tracy Fish Facility Direct Loss Mitigation Agreement
Integrated Storage Investigations, Fish Passage Improvement Program
Robinson Cattle Company**

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Introduction

The Merced River has been modified extensively over the years to provide agricultural and municipal water supply, flood control, power generation, agricultural development of the floodplain, and raw materials such as gravel products and gold. As early as the 1870s, farming interests built large canal systems to divert Merced River water for agricultural uses. In addition, several dams were built to regulate flows by storing runoff in reservoirs; the largest reservoir is 1,032,000 acre-foot Lake McClure, created by New Exchequer Dam in 1967. Finally, extensive gold and aggregate mining downstream of the dams left dredge tailings and numerous pits within the river corridor.

Manipulation of the river and its resources has led to loss and degradation of riparian and riverine habitat; in particular, salmon habitat has been affected in several ways. As mining companies excavated gravel, large in-stream ponds were created. These ponds provide ideal habitat for exotic fish species that prey on juvenile salmon. When the dams were built, access to spawning grounds upstream was lost to salmon; in addition, flows below the dams were altered temporally and in magnitude and temperature, and gravel was unable to pass them. The river can become “sediment starved” when the main source of gravel recruitment is lost, so higher flows must then recruit sediment solely from channel banks and beds. Over time this process results in channel degradation and armoring that, when combined with reduced flow and encroachment of vegetation, can narrow the channel and lead to abandoned floodplains. These effects make salmon reproduction and survival more difficult; an armored channel can limit effective spawning, and elevated water temperatures can lead to higher mortality.

The Merced River Salmon Habitat Enhancement Project (MRSHEP) consists of approximately 4 miles of the Merced River centered on the Highway 59 bridge near Snelling, California. Originally titled the Robinson/Gallo Project, the reach was identified in the Comprehensive Needs Assessment report (DWR, 1994) as having a high restoration priority for much of its length, and preliminary design work was begun in 1995.

Before the January 1997 flood event, the reach of the Merced River between the Highway 59 bridge and Snelling showed little evidence of channel bed degradation, although reaches both upstream and downstream of it appeared to be degrading (J. Vick, 1995). As much as 25 percent of the Merced River’s Chinook salmon spawning took place in the project reach (Pers. Comm. Bill Loudermilk, DFG, 1999). During the 1997 flood, the river breached the mining berms which had confined it to the historic channel; as a result, the river abandoned the historic channel in favor of a gravel pit with an invert approximately six feet lower. When the river abandoned the channel, all of the spawning riffles and much of the existing nursery habitat were lost.

This reach now looks quite different than it did before the flood event. Berms, created during mining of the floodplains, confined the channel to a narrow corridor separated from gravel pits. The earliest pits were created to provide gravel for the construction of Exchequer Dam and roads leading to Yosemite National Park (Pers. Comm. Chris Robinson, 12/7/99). Since the river breached most of the berms during the 1997 flood, it now travels for much of the reach through a wide, flat area and then flows into a series of broad shallow ponds (see Appendix A). The flat area lacks a defined channel and adequate alluvium in the bed, both of which are important elements in any functional alluvial stream. This situation interferes with the natural processes of the stream and creates many barriers to salmon survival. The wide, flat, shallow area presents both stranding issues during flow fluctuation as well as increased avian predation of smolts. The in-stream ponds provide habitat for predatory fish species and result in lower flow velocities. Young salmon may be forced to expend more energy to travel through the areas than they would if carried by the current. To some extent, the ponds also increase water temperature, particularly under low flow conditions. This temperature rise adversely affects the success of migrating adults and smolts.

Site Description

The Robinson Reach (Phase III) of the MRSHEP is located on the Merced River between river miles 42 and 44 just upstream of the Highway 59 bridge (Figure 1). It consists of reaches #1 and #2 of the MRSHEP (Figure 2) and an adjacent 2000 foot upstream reach. Both MRSHEP reaches were approved for funding in 1998 under the Delta Pumping Plant Fish Protection Agreement (Four Pumps), by CALFED, and by the Department of Fish and Game (Proposition 70 Funds). The reaches are described in Land Excavation Permit No. 597 and Conditional Use Permit No. 307. Additional funding for the entire project reach was approved in 2001 by CALFED, the Tracy Fish Facility Direct Loss Mitigation Agreement, and the Integrated Storage Investigations Fish Passage Improvement Program.

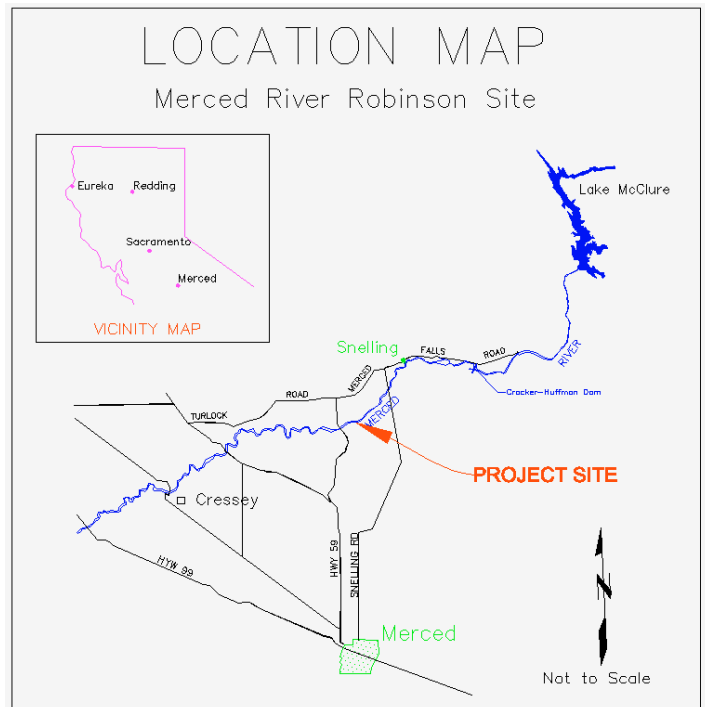


Figure 1 – Project Location

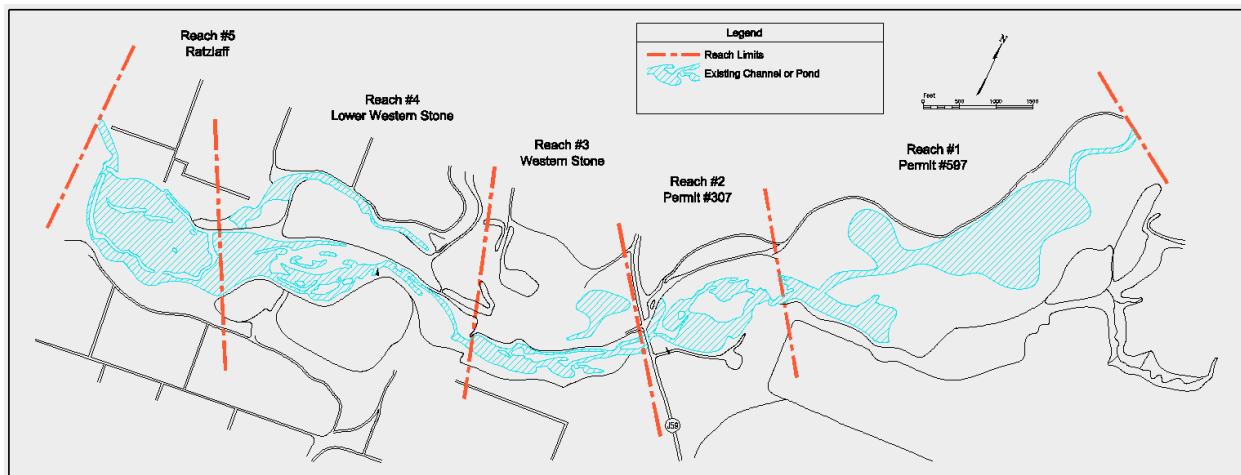


Figure 2 – Merced River Salmon Habitat Enhancement Project Overview

Phase III consists of three fairly distinct sections with different characteristics. The upstream reach, approximately from station 0+00 to 33+00 (Appendix D, Design Plan View Sheet 2), is characterized by an incised channel and large abandoned point bar.

Even very high flows remain confined in the channel. The central reach, stations 33+00 to 72+00, is a wide, flat, shallow reach where even the lowest flows spread out without a functional channel. The downstream reach is from station 72+00 to 116+00. It is more complex than other reaches, with alternating short gravel-bottomed channels and large in-stream pits. Throughout the Phase III project area, the river's path bypasses much of the pre-1997 channel; consequently, most of the coarse sediment and previously existing spawning and rearing habitat is also bypassed.

Goals and Objectives

The Merced River Salmon Habitat Enhancement Project is being designed and constructed in several phases over several years. Project staff is designing the project using similar methodologies for all phases to ensure compatibility. The goal of the MRSHEP is to have a continuous and functional river over the entire project reach.

The goal for Phase III of the project is to benefit the salmon of the Merced River by creating a more natural and functional reach with well defined channels and floodplains. Objectives include the following:

- eliminate or isolate juvenile salmon predator habitat;
- increase the quantity and quality of spawning habitat for chinook salmon;
- increase the quantity and quality of rearing habitat for chinook salmon;
- improve river and floodplain dynamics;
- create and enhance the riparian corridor;
- improve sustainability of the river;
- improve the adult and juvenile migratory path.

Project designers will achieve these objectives through several features of the design. Predator habitat will be eliminated by filling ponds, and the channel will be reconfigured to improve spawning and rearing habitat for salmon. River and floodplain dynamics will be improved by reconfiguring and scaling the channel to fit the post-dam flow regime. The design channel will include riffles, pools, and a meander that fits the approximate slope and design bankfull flow. Constructed floodplains will be replanted with native riparian vegetation and will contain simulated abandoned channels and backwater channels for diversity. These features will lead to an enhanced riparian corridor, improved sustainability of the channel, and an improved migratory path for salmon through the reach.

Hydrology

A study of the hydrology of the project reach on the Merced River was done prior to the construction of the Ratzlaff Project, also referred to as MRSHEP Phase II (first construction phase) (DWR, 2000). Post-dam flow frequency analyses were calculated for the Snelling and Cressey gages (Figures 3, 4). The Snelling gage is approximately 4 miles upstream of the project and the Cressey gage about 15 miles downstream.

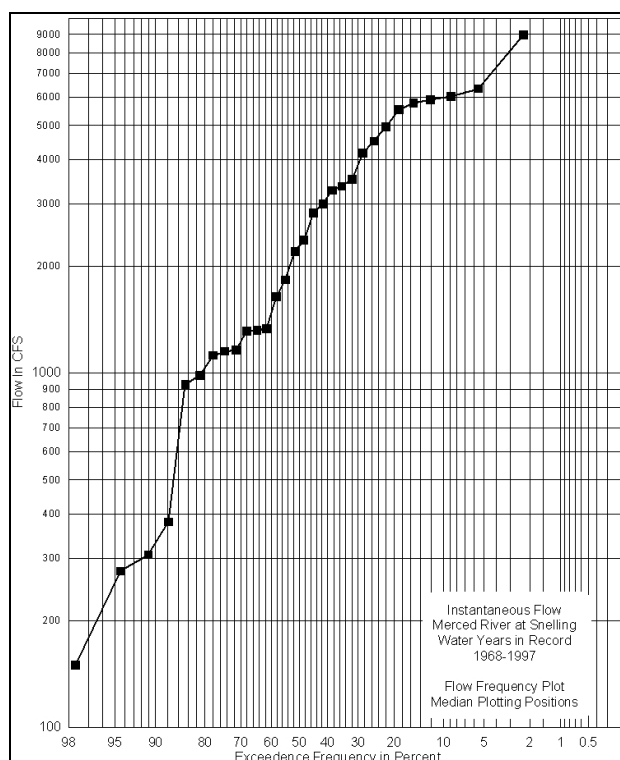


Figure 3 – Snelling Gage

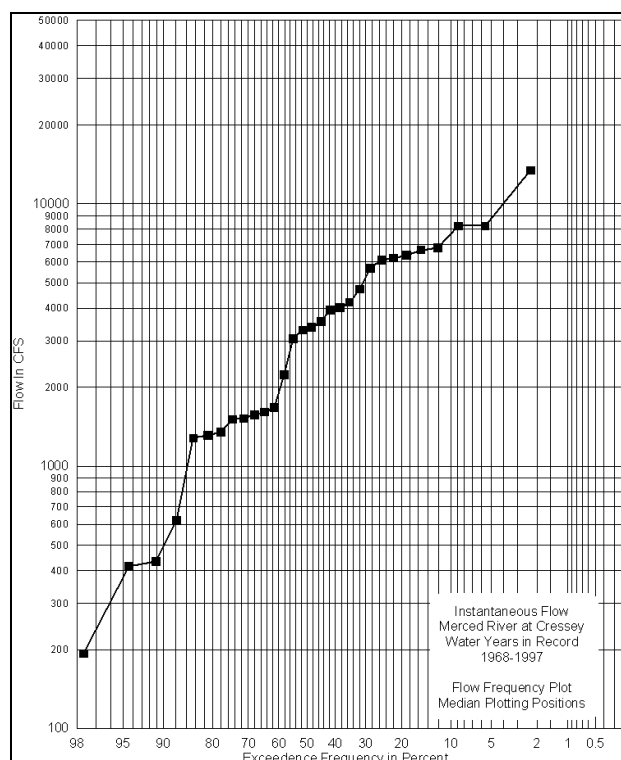


Figure 4 – Cressey Gage

Design Bankfull Flow

One of the most crucial features of a functional stream is the channel forming, or “bankfull”, flow. Bankfull is the flow in which a majority of the channel formation is accomplished. It is important both to determine what bankfull is and to scale the channel accordingly so that sediment transport will occur at proper times. Since several dams have been built in the last 100 years, the flow regime has changed substantially. Our task was to determine the current channel forming flow for the project reach and use it in the design process.

The method for determining bankfull discharge in a stream involves using a well-established stream gage with a long history of data collection. Most literature lists the predominant channel forming flow to occur with a frequency of 1.5 to 2.5 years

(Leopold, 1994). By using the flood frequency analyses shown in Figures 3 and 4, we were able to determine the range of flows that correspond to the necessary frequencies. Once we knew the flows, we obtained gage height data, rating tables, and shifts for both the Snelling and Cressey gages. Staff visited the gaging stations in November 1997 for an on-site determination of the bankfull discharge during the design process for the Ratzlaff Project (Phase II) (DWR, 2000). True bankfull discharge indicators probably do not exist in abundance on regulated streams, but some remnants were found near the gages which helped guide us in determining the best flow. By using both gage data and channel formation indicators, we determined the design bankfull flow to be 1,700 cfs.

Design Flood Flow

The maximum design flood flow is the highest flow under which the project should function normally. Higher flows are outside the scope of the project design, and their effects on the reach are unknown. The maximum design flood flow for this phase of the project is 8,000 cfs—a flow which was chosen after careful consideration during the design process for Phase II. Three flows were considered: 6,000 cfs, 8,000 cfs, and 12,000 cfs.

The lower flow, 6,000 cfs, was considered because it is the State Reclamation Board design flow for the reach of the Merced River within which the MRSHEP lies. Any flow above this exceeds statutory requirements and is beyond any anticipated flow release, although it was exceeded by at least 2,000 cfs in 1997. During January and February 1997, approximately 8,000 cfs (33 year flow event) flowed through the lower reaches of the Merced River causing some damage. According to the Army Corps of Engineers, the flooding resulted in more than \$8 million in damage on the river corridor (ACOE, 1999); in addition, the Highway 59 bridge was closed for several weeks due to fears of weakened footings.

Since the flow during the flood of 1997 was higher than the State Reclamation Board flow yet caused minimal damage, it is a good candidate for the project maximum design flood flow. In addition, the 8,000 cfs flow is likely to be the highest flow considered for re-operation of New Exchequer flood releases based on the 1997 floods (Pers. Comm. Ron Milligan, ACOE, 1999), and the frequency is similar to that which has been used on Tuolumne River restoration projects (15,000 cfs is about a 33 year event) (ACOE, 1999; DWR, 2000).

The 8,000 cfs flow maximum is more appropriate than 12,000 cfs (the maximum controlled release from New Exchequer Dam) for at least two reasons. First, the Merced Irrigation District prefers not to release the higher magnitude flows because they estimate that damage would result to power lines, sewer plants, some areas of the

town of Snelling, agricultural lands, local businesses, Caltrans facilities, and the Merced River Hatchery. Second, the river could breach and/or capture 550 acres (Vick, 1995) of mining pits near the river. Since these effects could be cost prohibitive, the use of the higher flow as a standard for the river is very unlikely.

Clay Hardpan Location

During early visits to the project site, staff observed apparent hardpan (heavy clay soil) exposures in a few locations; therefore, in January 1998, project staff excavated several test pits in an effort to estimate locations and elevations of the hardpan. Since the exposed portions were in the upstream half of the project, we concentrated our efforts in that reach. We reached hardpan at six of the nine sites excavated. Figure 5 shows the location of the pits and approximate elevation (ft MSL) of the hardpan as well as the locations of exposures.

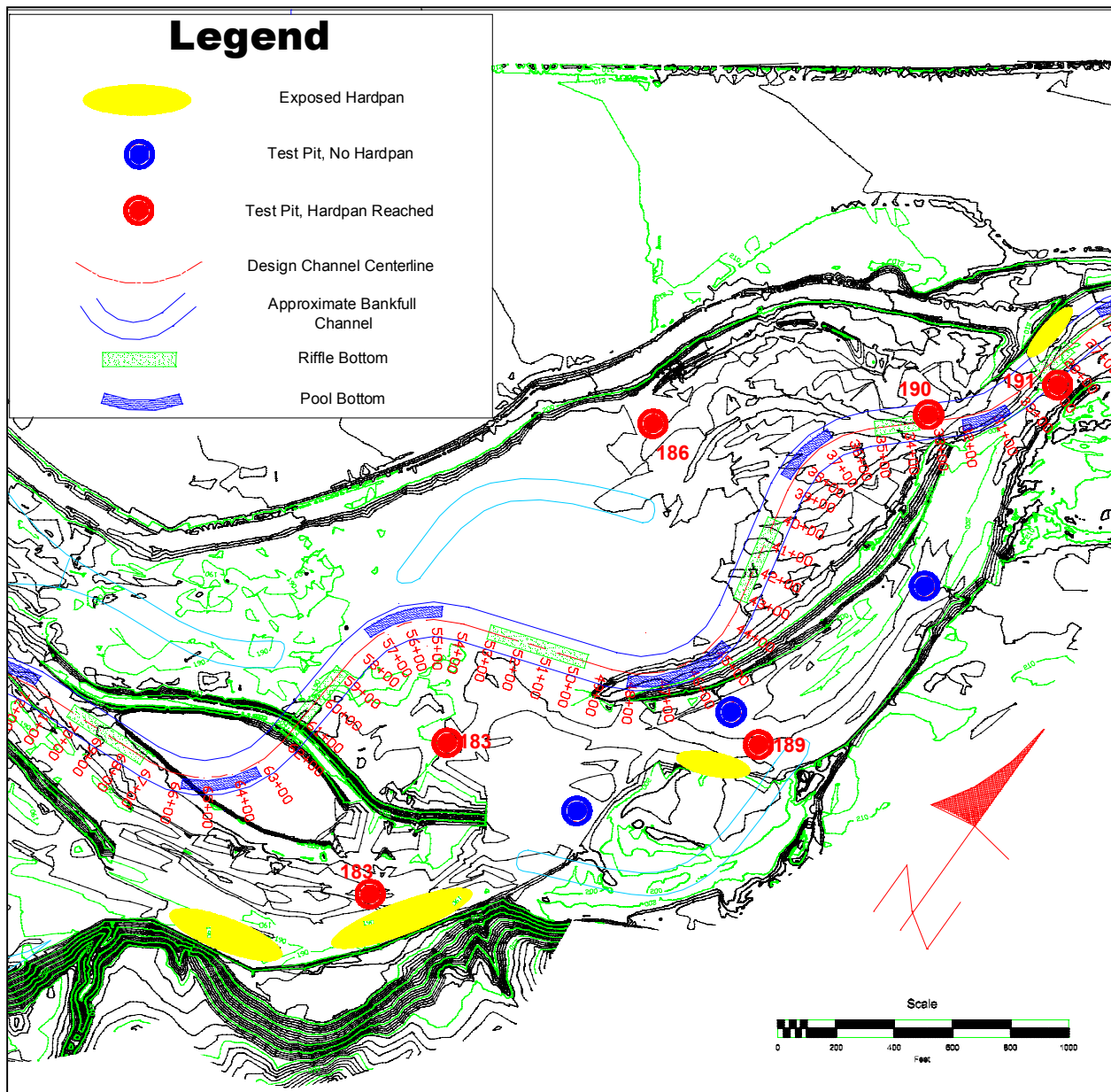


Figure 5 – Clay Hardpan Locations

While there is a looser soil with a high concentration of clay in much of the upper reach of the project, the denser hardpan layer is at a lower elevation than the design channel bottom. The plan to over-excavate the channel and backfill with suitable material (see Page 40 and Appendix D, Design Details sheet) will improve mobility in the reach by reducing the clay content but should not preclude the channel from migrating. It is possible that, while excavating the design channel, the contractor may encounter a hardpan outcrop which is at a higher elevation than expected. Should this occur, we will not realign the channel to avoid it; instead, the contractor will be directed to over-excavate the hardpan in the same manner as the looser clay soil. Although not the ideal solution, over-excavation would be an acceptable compromise since raising or realigning the channel at that stage would be cost prohibitive.

Project Design Parameters and Development

The design parameters of the project fall into three main categories; floodway, channel planform, and channel geometry. Floodway parameters include the general features of a river such as floodway slope and width, and floodplain detail features. Channel planform includes the various factors that go into designing the channel meander pattern, such as sinuosity, amplitude, and radius of curvature. Channel geometry includes the specific channel cross-section characteristics, such as depths and widths, for each type of channel feature.

Preliminary design in 1995 called for moving some of the existing berms back to create some minimal floodplain. Before any final design had been pursued, however, the 1997 flood changed the scope of work significantly. Several options were then considered, among them the chosen plan to use new berms to separate the river from some of the larger, deeper ponds. As more project funding became available, we expanded the project limits and were able to come closer to an ideal plan by eliminating the need for berms. The resulting draft plan called for channel realignment from station 4+00 to the Highway 59 Bridge.

We followed an open process in which we presented the design to stakeholders and peers who might have comments. After the preliminary design report was distributed, we called a series of meetings to which the parties were invited to discuss the project and any comments about the design. Two meetings included invitations to staff from CDWR, CDFG, USFWS, CalTrans, Stillwater Sciences, McBain and Trush, and the landowner. Some peer reviewers had concerns about performance of the steeper sloped upstream reach in high flows. After further consideration, and discussion during a third meeting with peer reviewers Jennifer Vick and Scott McBain, we decided to leave the existing channel upstream of station 23+00 intact since it has already shown to be relatively stable at high flows. The floodplain in that reach will be re-formed but the channel will remain as it is.

Floodway Parameters

Floodway parameters are some of the most basic and large scale characteristics of a river. They define the river by providing a foundation upon which the channel planform and geometry depend. The valley slope and floodway width influence what river characteristics will develop in a natural system, and floodplain features provide important diversity. These parameters, particularly the valley slope and floodway width, were among the first aspects of the project reach we studied since the more detailed design work depended heavily on them.

The valley slope, one of the most basic features of the river, depends on several factors. These factors include the pre-project valley slope, the upstream and downstream transition water surface elevations, and the amount of fill material available. Robinson Reach low-flow water elevations for the upstream and downstream transition points are approximately 198.0 feet (Sta. 23+00) and 180.0 feet (Sta. 116+00) respectively. The valley length is about 8,300 feet, so the average valley slope is 0.00217, or 0.217%. Since much of the gravel in the reach has been mined out, fill sources are limited. The existing valley geography, coupled with a lack of fill material, requires a varied valley slope through the reach. To accomplish this we designated four reaches within the project, each with its own characteristic valley slope and channel dimensions. The 1,700 foot reach furthest upstream will fall 6.5 feet for a slope of 0.0038. The second reach will fall about 3.2 feet over 1,100 feet (slope = 0.0029), the third 1,600 foot reach will fall 4.3 feet (slope = 0.0027), and the downstream 5,600 feet will fall 10.4 feet (slope = 0.0019). These values can be found in Table 1.

Reach	Valley Length (ft)	Drop (ft)	Slope
1 (6+00 to 23+00)	1,700	6.5	0.0038
2 (23+00 to 35+00)	1,100	3.2	0.0029
3 (35+00 to 54+00)	1,600	4.3	0.0027
4 (54+00 to 116+00)	5,600	10.4	0.0019

Table 1 – Valley Slope By Reach

Floodway width is a factor that has a profound effect on the overall design since the path chosen for the channel will depend on how much space there is for it to meander. It also determines how deep the river will be at high flows. The geography of the Robinson Reach is such that there will be ample width for floodplains and floodway features. The available width varies from a maximum of 1,600 feet down to a minimum of about 750 feet, excluding the 400 foot width beneath the Highway 59 bridge. The California Department of Transportation currently plans to widen the bridge opening by about 100 feet. This modification will increase the width beneath the bridge to over 500 feet, and as a result will help reduce the encroachment effects at high flows evident in Appendix H.

The wide floodway will allow other features to be included which will add important diversity and aesthetic value to the floodplains. We will use several features in the areas on either side of the channel; Simulated Abandoned Channels (SACs), a shallow pond, and a backwater channel (Appendix D, Design Plan Views). The first feature, the SAC, can be described as a partially filled channel remnant placed in the floodplain to simulate a channel which has been abandoned by the river. As the Design Details sheet shows in Appendix D, we have designed the SACs to be approximately 80 feet in width and two to three feet deep. We will include several sections of SAC in the wider areas of the floodplain where they will have sufficient separation from the main channel,

and lengths will vary depending on the floodplain area and main channel location. The second feature, the shallow pond, is planned for the northern floodplain in the downstream half of the project (Appendix D, Design Plan View Sheet 1) and will neither be directly connected to the channel nor exceed the depth of the channel pools. This feature will lend diversity to the floodplain and will allow establishment of wetland species on the project site. The last feature, the backwater channel, is a feature found in many river systems; indeed, it was present in the Robinson Reach before gravel mining disturbances (Figure 6). So that we may simulate these features, we designed a backwater channel that has a deeper invert than the SACs, which will allow water to be in most of the channel all year (Appendix D, Design Details sheet). We will place the backwater channel on the south side of the floodplain so that it extends from the main channel to the bluffs.

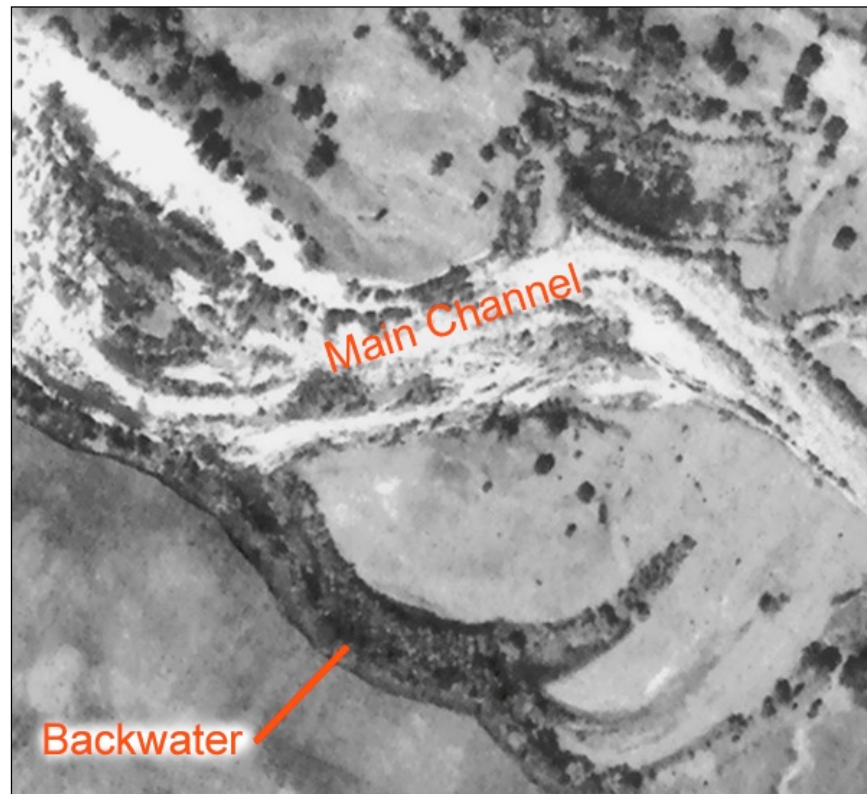


Figure 6 – Backwater and Channel, 1946

Many of the floodplain features described were affected by our decision to implement a design which did not require levees or berms to isolate sections of the floodway from the river. This decision allows us to have a wider floodplain with more diverse features. The California Department of Transportation's decision to increase the span of the Highway 59 bridge, which crosses the river at the downstream end of the project, will also improve the floodplain dynamics in the reach by improving performance at high flows. For example, it will improve sediment transport since a narrower floodplain

increases material-moving forces in the channel. Since these forces will be reduced, the smaller gravel will not be carried out of the reach at relatively low flows.

Channel Planform

The channel planform parameters include channel slope and meander. The average channel slope in a meandering stream is lower than that of the floodway slope, and it cannot be determined until the floodway slope is known. The meander of the channel, or sinuosity (the ratio of channel length to valley length), is the channel planform characteristic we started with once we knew the design floodway parameters. This characteristic had to come first because the channel slope depends on how much sinuosity the channel has. Since the project is broken into reaches based on the slope of the floodway, we had to vary the channel parameters according to those features.

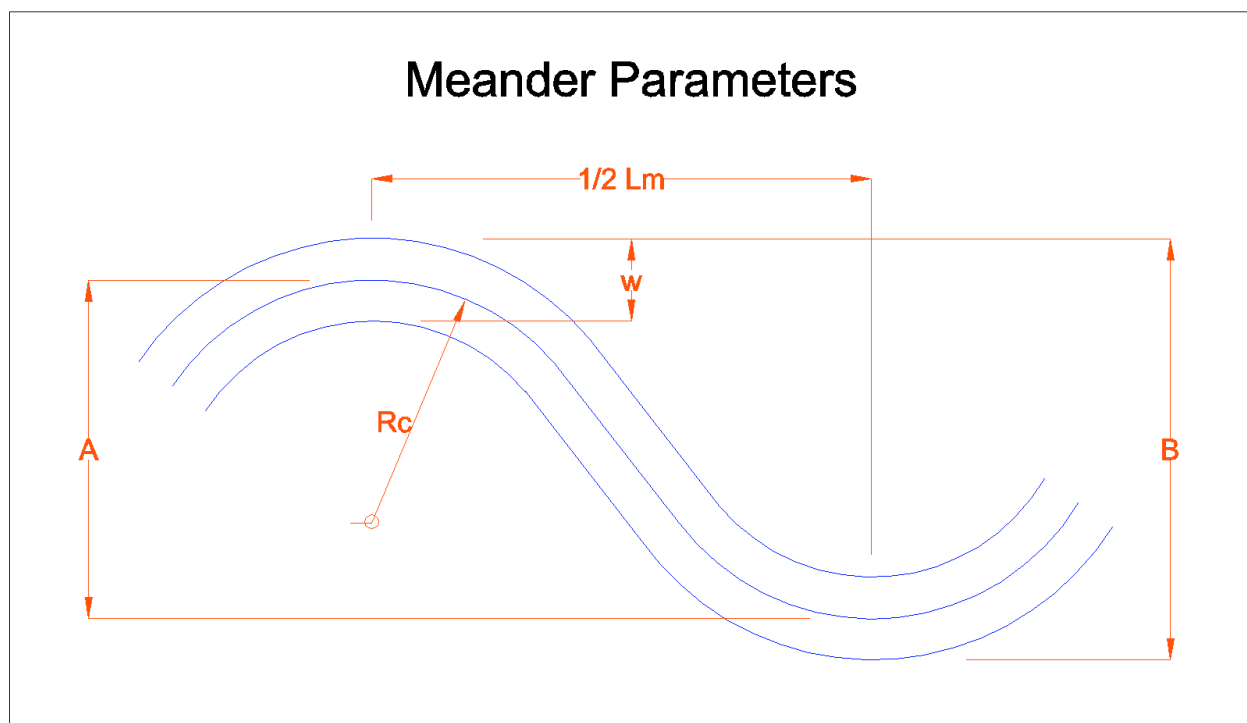


Figure 7 – Meander Parameters

Sinuosity is affected by, and related to, several other parameters: meander length (L_m); amplitude (A); belt width (B); radius of curvature (R_c); channel slope; and, to an extent, channel width (w). The planform attributes are shown graphically in Figure 7. The channel width must be an estimate until the true channel slope has been determined.

The geomorphic features of the project reach, as estimated from 1946 aerial photos, once included a meander length of 3,500 feet, an amplitude of 1,500 to 2,000 feet, a channel width of 250 feet, and a sinuosity of 1.26. According to Vick (1995), the

bankfull flow for this period was about 4,700 cfs, and the average historic active channel width was 257 feet. The most basic difference between the 1946 river and the present river, besides the mining, encroachment, and gravel recruitment, is the change in flow regime. The current design bankfull flow is approximately 1,700 cfs, or about thirty-six percent of the historic flow (page 8). The drop in bankfull flow affects nearly every aspect of the river, however the sinuosity should not necessarily change. Since the amplitude of meanders is determined more by the erodibility of the stream banks than by any hydrodynamic principle (Leopold, et al. 1964, p297), the sinuosity is likely to be similar for both regimes as long as the valley slope and the mobility of the bed and bank material are similar. Dave Rosgen shows a relationship between clay content in channel banks and the corresponding sinuosity of the channels (Rosgen 1996, p. 2-8). This relationship implies that bank materials can predict sinuosity. We assumed that the bank and bed material will be of a size to be mobile at the modeled flow, since we will try to use material of suitable size in the channel. Our plans call for graded material, sized for mobility, to be placed on either side of the design channel throughout most of the reach (Appendix D, Design Details sheet).

Many of the channel parameters are related directly to the bankfull width. Since it was impossible to know exactly what the bankfull width would be until other parameters were determined, we used an estimate of 120 feet (the width used in MRSHEP Phase II). The meander belt width, B (Figure 7), for this stream type should be 4 to 20 times the bankfull width, or 480 to 2,400 feet. The average should be 11.4 times bankfull width, or 1,350 feet (Rosgen 1996, p 4-9). Measurements we made at the upstream end of the project gave us a meander belt width of about 420 feet. Some of the outside banks of the bends in that reach have apparently recently eroded, so it is reasonable to assume the reach is still in a state of change and would increase the belt width over time (see Figure 12). The meander amplitude, A, is similar to the belt width but is measured from the channel centerline. For a river with a bankfull width of 120 feet, the amplitude would be the belt width value minus 120 feet. The formula $A = 2.7 w^{1.1}$ (Leopold, et al. 1964 p297) gives a value of 523 feet for the amplitude, for a belt width of about 640 feet. Since the maximum width of the project reach is about 1,600 feet, the belt width should be within 480 to 1,600 feet, and amplitude should be 360 to 1,480 feet.

Meander length can be related to the belt width and bankfull width through the equations $B=0.61*L_m$ (Williams 1986, p158), $L_m=10.9w^{1.01}$ (Leopold 1994, p59), and $L_m=10.31w$ (Dury 1976, p234), where B is the belt width, L_m is the meander length, and w is the bankfull width. The first equation gave a range for the meander length of 790 to 3,900 with an average value of 2,200 feet. Based on the estimated bankfull width of 120 feet, the second equation resulted in a meander length of 1,370 feet and the third in 1,240 feet. The meander wavelength of the upstream portion of the project reach was

on average about 1,450 feet, and since it fell within the ranges calculated above, seemed to be an appropriate value to use in the design.

The radius of curvature can be approximated using the equation $L_m = 4.7R_c^{0.98}$ (Rosgen 1996, p2-6) or the equation $R_c = 0.22L_m$ (Williams 1986, p158). We calculated a radius of curvature of about 345 feet using the first equation, while with the second the result was 320 feet. A value of 350 feet for the radius of curvature was chosen for the project design.

Using the results of these calculations and observations, we developed a guideline for designing the layout of the channel. We had to determine what part of the range of the meander amplitude to use based on the valley slope, material size, and geographical constraints, and using a radius of curvature of 350 feet and a meander length of 1,450 feet. Since the project reach is heavily encroached at the upstream end, as well as at the bridge, we decided to use the lower end of the calculated range for meander amplitude--approximately 350 feet. Somewhat lower than the historic value of 1.26, the resulting project sinuosity will be 1.14; however, it is likely that the channel in the far

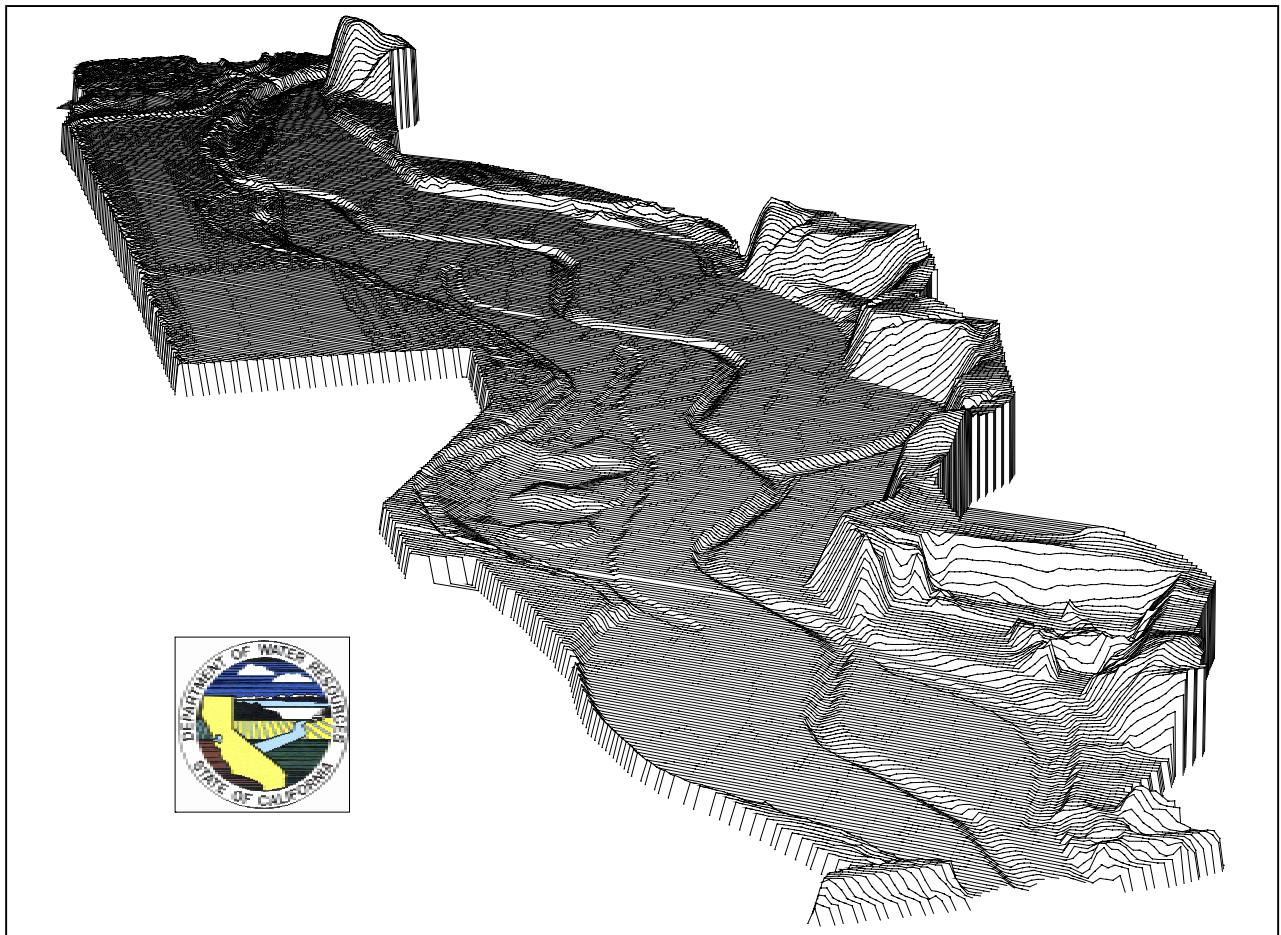


Figure 8 – Perspective View, Design, Looking Upstream

upstream reach will continue on its apparent southern migration, eventually increasing the sinuosity in that reach. Figure 8 is a perspective view of the design which shows the channel planform and floodplain features. A comparison of this perspective view with the pre-project perspective is located in Appendix B.

Channel Geometry

Channel geometry features like depth and width must be determined for the design riffles and pools. These features, combined with channel slopes, control both the velocities and depths at which water will flow through the channel and the channel's ability to move sediment.

We based the shapes of the sections on those used in the MRSHEP Phase II (DWR, 2000). Section geometry varies from that project, and from reach to reach in this project, based on the channel slopes we assigned to each reach of the project. We used the valley slopes and channel planform to determine average channel slopes in each reach, and we assigned slopes to the riffles and pools based on those average slopes. Staff calculated average channel slopes of 0.0029 for Reach 2, 0.0023 for Reach 3, and 0.0017 for Reach 4 (Table 2). In Reach 2, we assigned a 0.004 slope to riffles, a 0.0015 slope to pools, and to transition sections a slope of 0.003. For Reach 3, the riffle slope was 0.0035, the pool slope was 0.0015, and the transitions sloped at 0.002. The downstream reach, Reach 4, ended up with a riffle slope of 0.0025, a pool slope of 0.001, and a transition slope of 0.0014. These slopes can be found in Table 2. The profile view of the channel invert and floodplains, along with the approximate existing thalweg profile, is shown in Figure 9.

Reach	Avg Slope	Riffle Slope	Pool Slope	Trans. Slope
2 (23+00 to 35+00)	0.0029	0.0040	0.0015	0.0030
3 (35+00 to 54+00)	0.0023	0.0035	0.0015	0.0020
4 (54+00 to 116+00)	0.0017	0.0025	0.0010	0.0014

Table 2 – Design Channel Thalweg Slopes

We determined dimensions for each type of design section using both the Chezy-Manning equation and the surface roughness equation. The surface roughness equation,

$$v = (gHs)^{1/2}(5.65\log(H/D_{84})+2.83)$$

where g is the acceleration of gravity, H is the average depth, s is the slope, and D_{84} is the particle diameter at which 84% of the particles are smaller, is used to determine depth at spawning flows since it does not take into account the effect of vegetation on

roughness. The Manning equation is used for higher flows. Using these equations, we estimated depth, width, and side slopes for the channel.

Appendix C contains the various design cross-section templates we developed, and some of the characteristics of each section are shown in Table 3. Reach 2 will have a bankfull (1,700 cfs) width of 110 feet for riffles and 111 feet for pools. Bankfull depths will range from 4.2 feet to 6.3 feet. Riffle water depth at spawning flows (225 cfs) will be about 1.5 feet. Reach 3 will have a bankfull width of 112 feet for riffles and pools, and the bankfull depth will range from 4.3 to 6.4 feet with spawning depths at about 1.5 feet. Throughout Reach 4, the bankfull width will be 116 feet for riffles and 112 feet for pools. Bankfull depths will range from 5.3 to 6.4 feet, and riffle depths at spawning flows will be about 1.9 feet. Riffles in Reaches 2 and 3 will have 50 foot bottom widths, but in Reach 4 will have a bottom width of 40 feet for improved sediment transport characteristics.

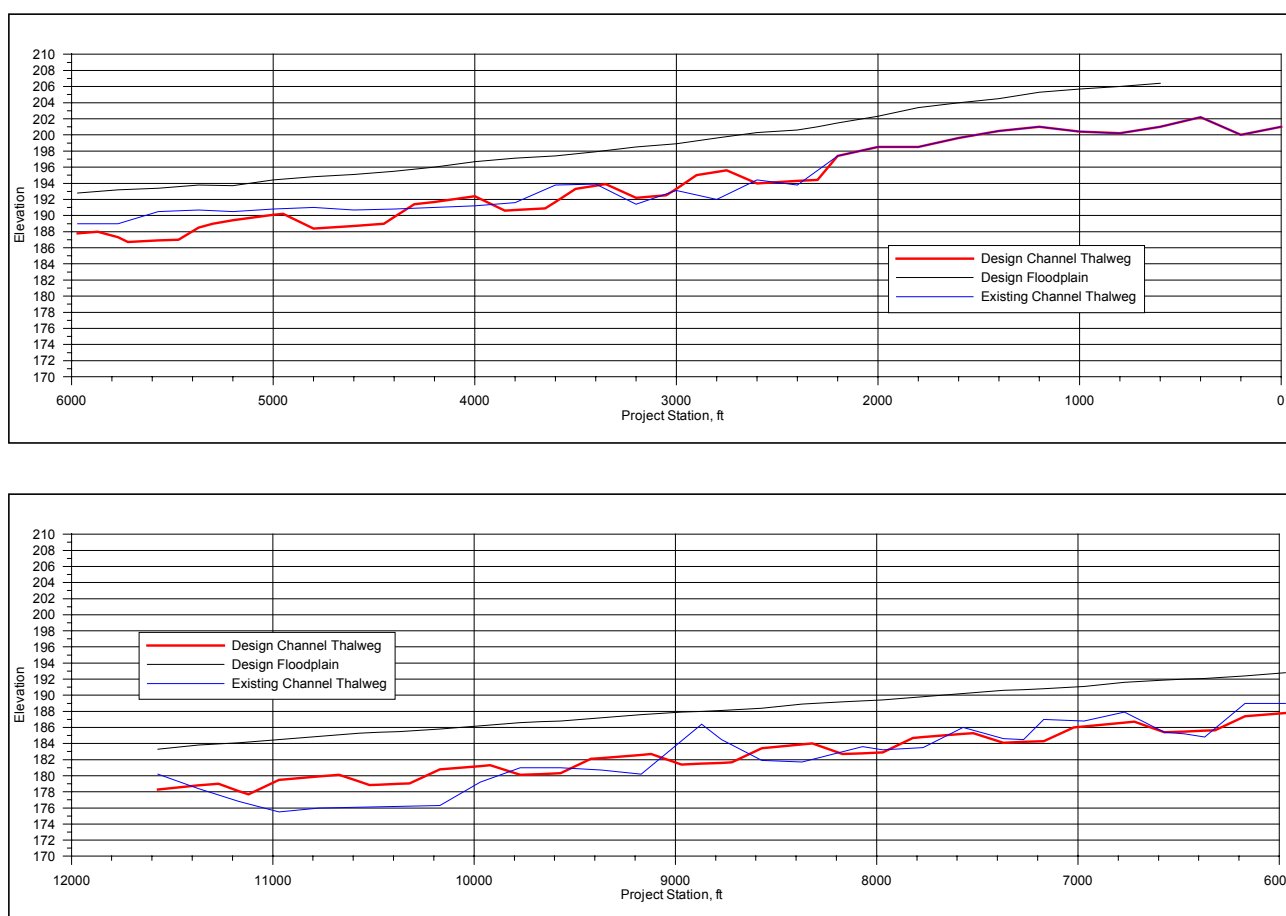


Figure 9 – Thalweg Profiles

Reach	Q = 225 cfs (Spawning flow)			Q = 1,700 cfs (Bankfull flow)		
	Width (ft)	Depth (ft)	Velocity (ft/s)	Width (ft)	Depth (ft)	Velocity (ft/s)
Reach 2 Riffle	56	1.5	2.81	110	4.2	5.59
Reach 2 Pool	67	2.7	1.11	111	6.3	3.70
Reach 3 Riffle	56	1.5	2.81	112	4.3	5.40
Reach 3 Pool	69	2.8	1.10	112	6.4	3.61
Reach 4 Riffle	48	1.9	2.65	116	5.3	4.30
Reach 4 Pool	71	3.0	1.36	112	6.4	3.54

Table 3 - Widths, Depths and Velocities of the Design Channel

Observations of the lower Merced River have shown an optimum depth for salmon spawning to be greater than 0.9 feet, and the optimum velocity to be between 1.3 and 2.1 ft/sec with a usable range of 0.6 to 3.4 ft/sec (USFWS 1997, p13). Other studies have shown spawning depths of greater than 0.5 feet (DWR 1992), 0.8 feet (USFWS 1986) and greater than 1.5 to 2.5 feet (USFWS 1982) to be required (Figure 10). The DWR report and the California Fish Bulletin No. 164 (Lietritz et. al. 1980) list preferred velocities of 1.5 to 2.5 ft/sec, while the optimal velocities listed in the 1986 USFWS report range from 1.0 to 3.0 ft/s (Figure 11).

We have estimated that the design depths at spawning flows will be 1.5 to 1.9 feet (Table 3), which is within the above referenced optimum ranges. Velocities will range from 2.65 to 2.81 ft/sec, which is slightly higher than the velocity ranges in DWR 1992 and Bulletin 164, but within the 1986 USFWS and the 1997 USFWS usable ranges. These design values are narrow in range because the design riffle sections are similar throughout the project; however, the range will likely broaden as the river adjusts in the future.

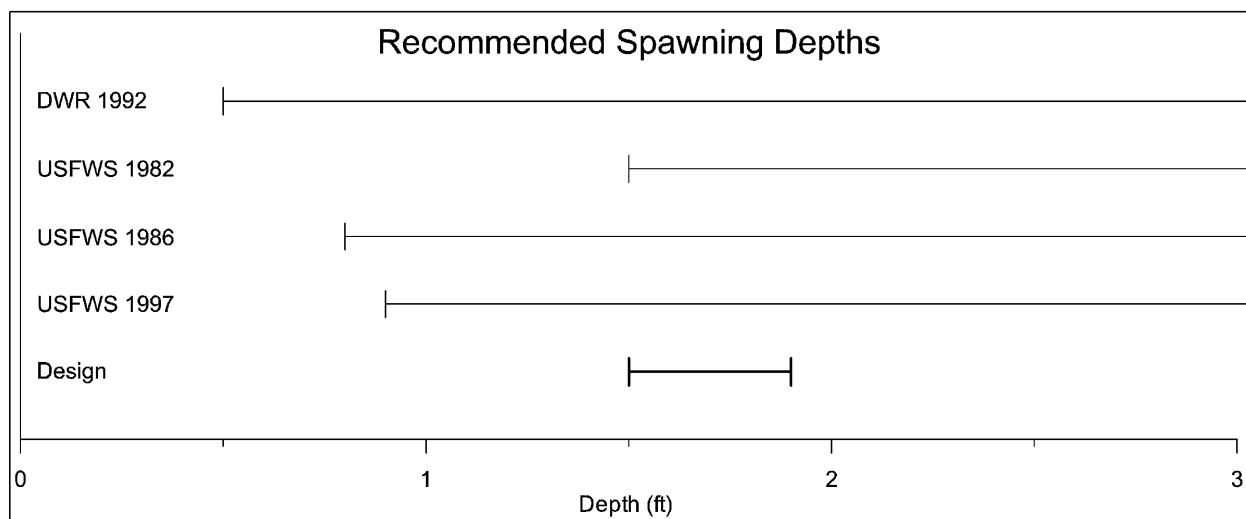


Figure 10 – Spawning Depths

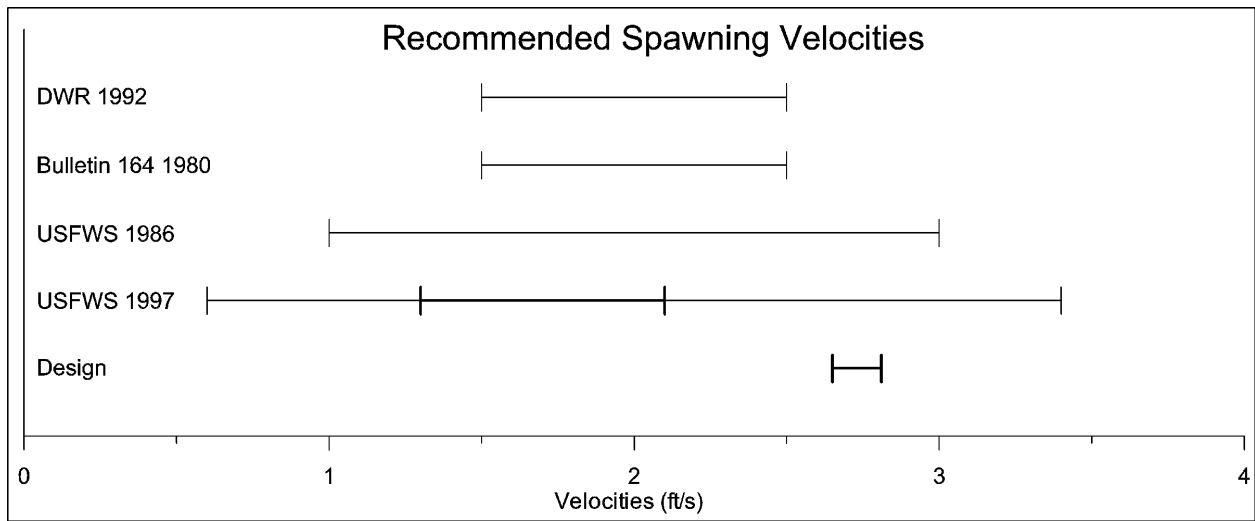


Figure 11 – Spawning Velocities

Project Characteristics

In summary, the project characteristics are:

Project:

- Valley Length: 9,500 feet
- Project Area: 310 acres
- Existing Pond Area Removed: 55 acres

Channel:

- Length: 11,600 ft
- Low Flow: 225 cfs
- Low Flow Depth: 1.5 ft (riffles) to 3.0 ft (pools)
- Low Flow Width: 56 to 71 ft
- Design Bankfull Flow: 1,700 cfs
- Design Bankfull Depth: 4.2 ft (riffles) to 6.4 ft (pools)
- Design Bankfull Width: 110 to 116 ft
- Design Bankfull Average Velocity: 3.5 to 5.6 ft/s
- Design Flood Flow (minimum): 8,000 cfs
- Design Flood Flow Depths: maximum of 8.6 ft (riffles) to 9.5 ft (pools)
- Design Flood Flow Average Velocities: 2.9 to 4.0 ft/s
- Floodplain Width: 420 (bridge) to 1,600 ft
- Meander Wavelength: 1,450 ft
- Total area suitable for spawning (as per Figures 10 and 11): 17,800 yd² constructed, and up to 14,000 yd² improved

We will attempt to maintain a sediment balance within the reach (sediment in = sediment out) by including coarse sediment infusion sites along the project length. The sites will be determined during construction of the project and selected based on availability of access and potential for material transport. Since transport is expected to be greater at the upstream reaches, the infusion sites will most likely be located there. The D₈₄ particle will be mobile and floodplains will be inundated during a 1.5 to 2.0 year event.

Although on-site material exists which is suitable for use in the constructed channel, site surveys show that a large portion of the proposed alignment will pass through areas which have been mined of gravel resources leaving mostly clays. Approximately 2,800 feet of the proposed channel will require some substrate replacement so that an adequate and stable base for spawning riffles, runs, and pools will be produced (Appendix D).

Sediment Transport Studies

DWR performed a sediment transport study to help us determine the hydraulic conditions which cause incipient motion of the bed surface in the project reach. One approach for this type of study involves establishing appropriate cross-sections, surveying them, and performing pebble counts at them. Pebble counts are necessary so that the existing D_{84} can be identified and used to calculate the flow which mobilizes it—a flow which is also recognized as that which is needed to produce a morphological change in the reach. Another approach is to reverse the process by estimating the diameter which would be mobilized in the cross-section at a given flow. The estimate can then be tested and verified using tracer gravel in the channel.

We chose a reach of the channel at the upstream end of the Robinson Project area as the location for a sediment transport study. We chose this site because it is a fairly straight reach which has shown evidence of recent bed movement and contains well developed riffles. The reach is approximately 1000 feet long with three study cross-sections 400 to 500 feet apart (Figure 12).

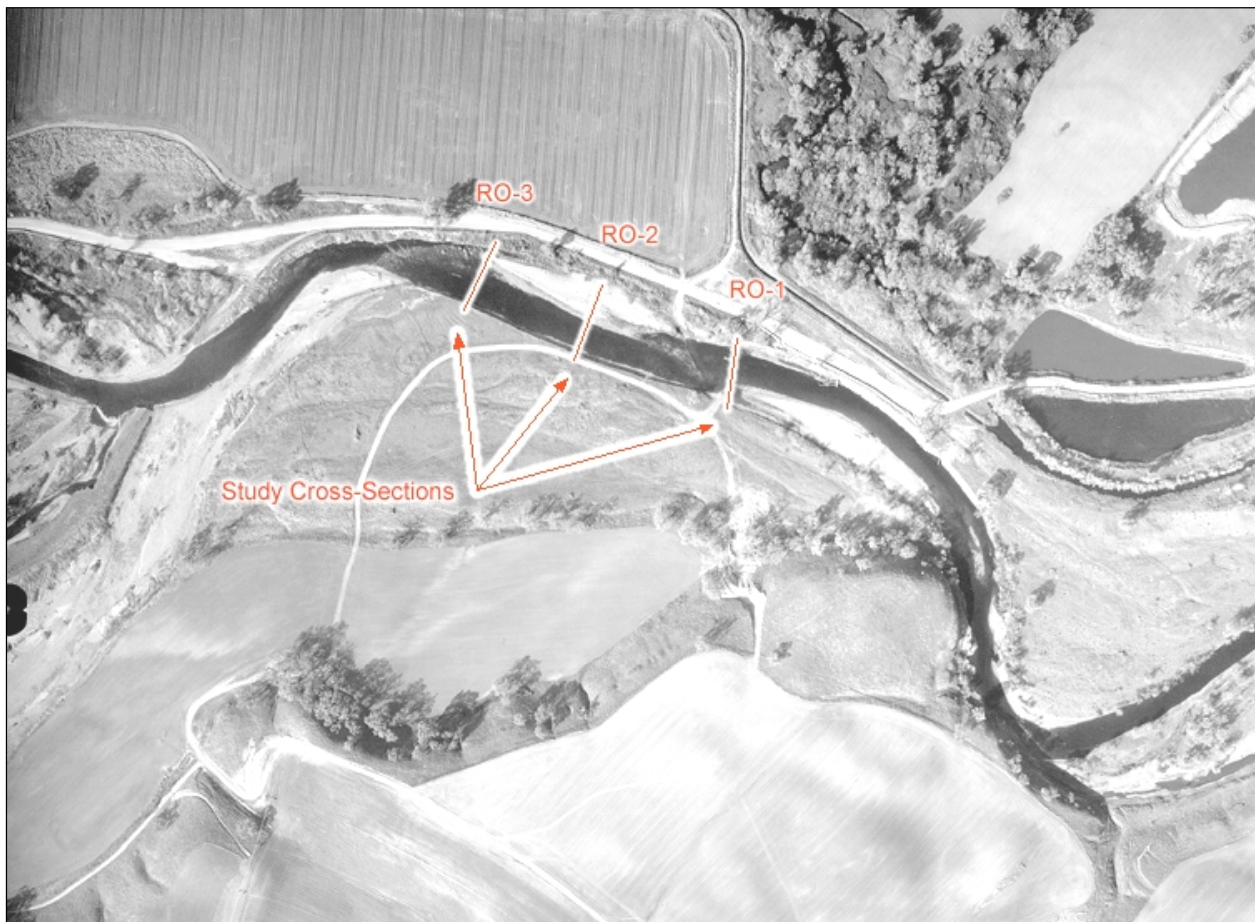


Figure 12 – Sediment Transport Study Site

Theory

A model for the sediment transport characteristics of a channel can be created once the particle size distribution, water surface slope, and cross-sectional geometry are known. The hydraulic radius, which is used in the Manning Equation to calculate flow, is estimated from the equation $\tau = r g R S$, where r is the density of water, g is the acceleration of gravity, R is the hydraulic radius, S is the water surface slope at a given flow, and τ is the shear force on the bed particle. The value of τ in this equation comes from the Shields Equation,

$$\tau_i = 1.65 \tau_{ci}^* g D_i$$

where D_i is the particle size in millimeters, and τ_{ci}^* is the dimensionless shear.

The value of τ_{ci}^* depends on where the particles are in the channel bed. The Andrews model,

$$\tau_{ci}^* = 0.0384 (D_i / D_{50})^{-.887}$$

where D_{50} is the size of the 50th percentile particle in millimeters, can be applied when a particle has been naturally deposited in the channel bed (Andrews 1994, p2247). For a particle laid on the surface of the bed, such as a tracer pebble, the Andrews model does not apply. A lower value for τ_{ci}^* in the Shields Equation may be used in this case to more accurately estimate the mobilizing shear. In general, for particles in the D_{84} range a value of 0.02 to 0.025 would be appropriate, with 0.02 being the minimum viable value for τ_{ci}^* . For smaller particles (D_{50} or smaller) a value of 0.03 to 0.045 would be appropriate. These values should be used instead of those calculated from the Andrews model since Andrews applies to particles within the bed. When tracer gravel is placed, it is virtually impossible to simulate naturally placed material, and the particles tend to sit on the surface of the bed. Therefore, the shear force necessary to move the particle differs from what would be expected using the Andrews Model. Andrews stated that motion of particles begins when τ_{ci}^* is as small as 0.02 when they are resting in the shallowest bed pockets, which would be the case for tracer gravel placed on the bed surface (Andrews 1994, p2241). Where particles are placed naturally, large particles tend to “shadow” smaller ones making them more difficult to move, so a higher τ_{ci}^* for the smaller particles is required to more accurately predict movement.

December 1999 Experiment

Initial calculations required a knowledge of the cross-section geometry, bed material sizing, and slope of the reach. In November 1999, DWR staff surveyed the cross-sections shown in Figure 12 (surveys in Appendix E) and performed pebble counts (Appendix F). We designated the sediment transport study cross-sections, starting upstream, as RO-1, RO-2, and RO-3. The D_{84} and D_{50} at section RO-1 were 110 and

70 mm respectively, at section RO-2 they were 170 and 100 mm respectively, and at section RO-3 they were 170 and 115 mm respectively (Table 4).

We determined the flow required to mobilize the D_{84} particle at each section using the Andrews model and methods described in the Theory section (Table 4). For sections RO-1 and RO-3, we calculated flows of 6,500 and 8,000 cfs respectively. This seemed reasonable since the most recent peak flows in the reach topped out at approximately 8,900 cfs with sustained flows of 8,000 cfs (Jan. 1997, Snelling), and there was obvious movement of the bed during that event. The middle section, RO-2, required a higher flow for mobilization according to our calculations—about 9,400 cfs.

Section	Existing D_{84}	Existing D_{50}	D_{84} Mobilizing Flow
RO-1	110 mm	70 mm	6,500 cfs
RO-2	170 mm	100 mm	9,400 cfs
RO-3	170 mm	115 mm	8,000 cfs

Table 4 - Study Section D_{84} , D_{50} and Mobilizing Flows

The particle size which would mobilize at a given flow can be estimated by reversing the calculation process. First, the water elevation which corresponds to the given flow is determined through an iterative process. Once the elevation is known, the particle size that will begin moving at that flow can be estimated using the equations in the theory section. We made initial estimates of 51mm for RO-1 and 47mm for RO-3 for the first tracer gravel trial. The first set of tracer gravel was placed in December 1999, and it was recovered in April 2000. During recovery, we measured the distance of the rocks from baseline, and we documented where they were found laterally. We limited the recovery area to 100 feet below the cross-section, and we broke the width of the channel into five zones. Only cross-sections RO-1 and RO-3 were used after the initial placement of tracer gravel because we determined that RO-2 was at a developing pool section. It did not meet the necessary requirements for this type of experiment, which is best conducted on a straight riffle type section where shear forces on the bed material will be similar all across the channel. The Merced River flows during this period reached in excess of 3,700 cfs, with sustained flows of 3,200 cfs. The smaller tracer gravel, which was calculated for much lower flows, was moved extensively by the river during this event, and most of the placed rocks were difficult to locate (Figures 13, 14).

Figure 13 shows cross-section RO-1 and the results of the tracer gravel recovery in April, 2000. Staff recovered only ten of the fifty 51mm rocks originally placed. The recovered rocks moved an average of 38 feet, and the bulk of the unrecovered rocks are assumed to have been transported beyond the 100 foot limit of our recovery area.

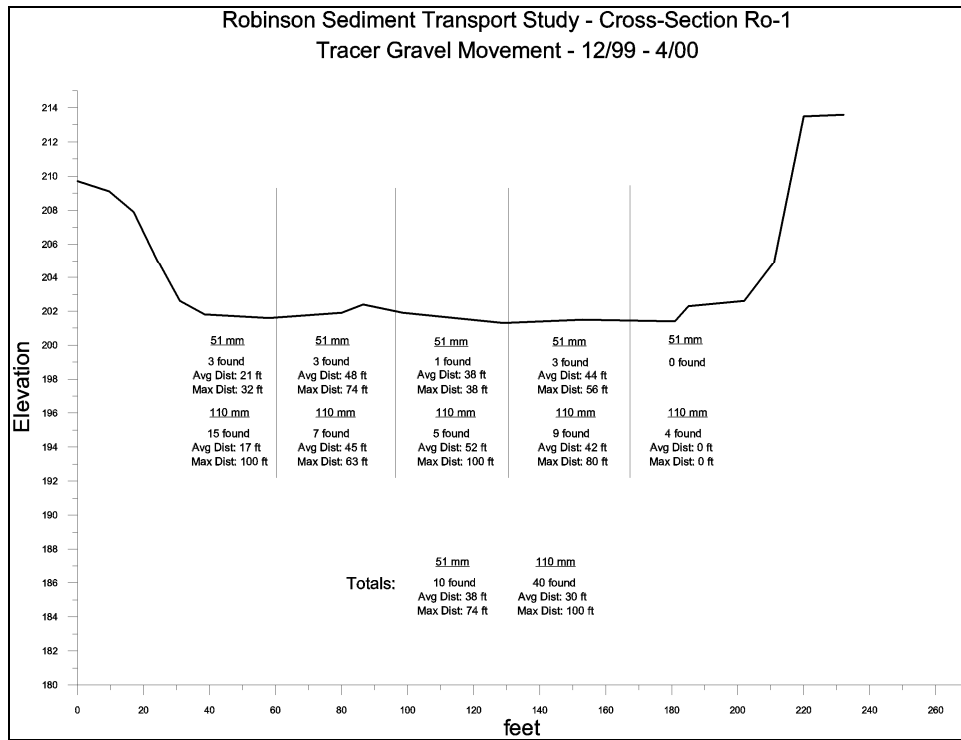


Figure 13 – April Results, Section RO-1

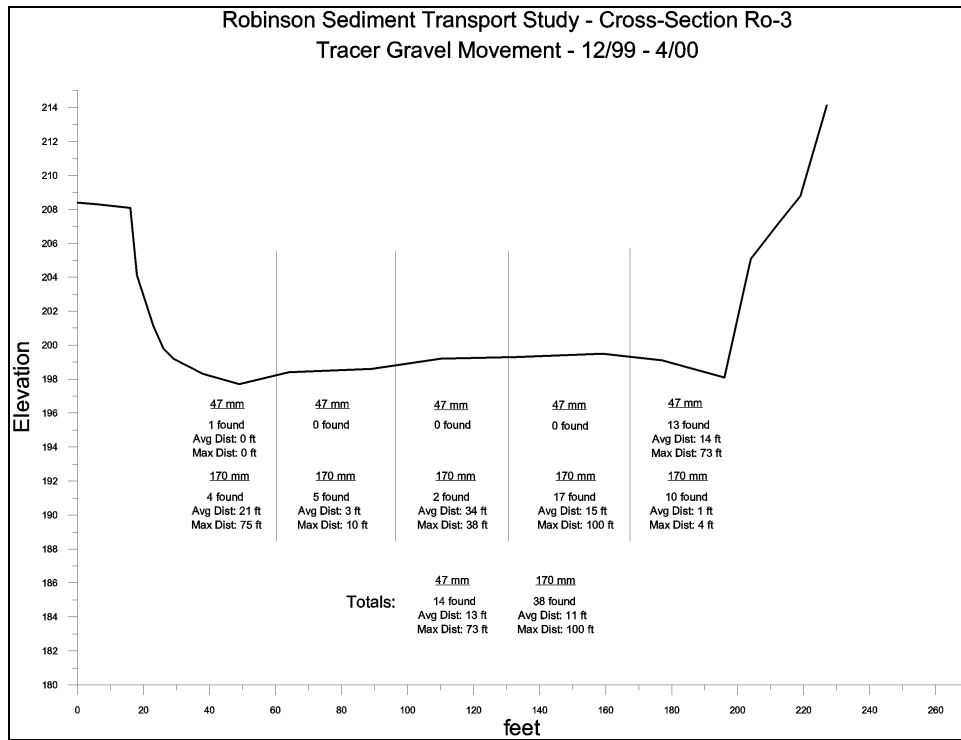


Figure 14 – April Results, Section RO-3

Figure 14 shows the same data for cross-section RO-3. At that section, staff recovered fourteen of the original fifty 47mm rocks which had an average distance traveled of 13 feet. We assumed that the bulk of the unrecovered rocks at this section were also transported beyond the 100 foot recovery area.

Figures 13 and 14 also show the recovery and movement data for the D_{84} particles placed in the cross-sections. At section RO-1, forty of the fifty placed rocks were recovered, with an average movement of 30 feet. At section RO-3, thirty-eight of fifty rocks were recovered which had an average movement of 11 feet.

April 2000 Experiment

Upon recovery of the tracer gravel from the first experiment, staff placed a new set of particles. We did not expect flows to be as high as they were during the first trial, so 60mm rocks were estimated to be appropriate. Placement procedure for this experiment differed somewhat from the December one in that the rocks were "stomped in" in an attempt to better simulate bed material motion. Staff placed the gravel particles on April 12th, 2000 and recovered them on May 24th, 2000. During that period the river experienced flows of up to 2,500 cfs, with sustained flows of 2,300 cfs. The results of the recovery can be seen in Figures 15 and 16. At section RO-1 the gravel moved an average of seven feet, and 72 of the 75 placed particles were found. At section RO-3 all 77 placed particles were found, with an average distance traveled of zero feet. Only five rocks were found to have moved further than 2 feet.

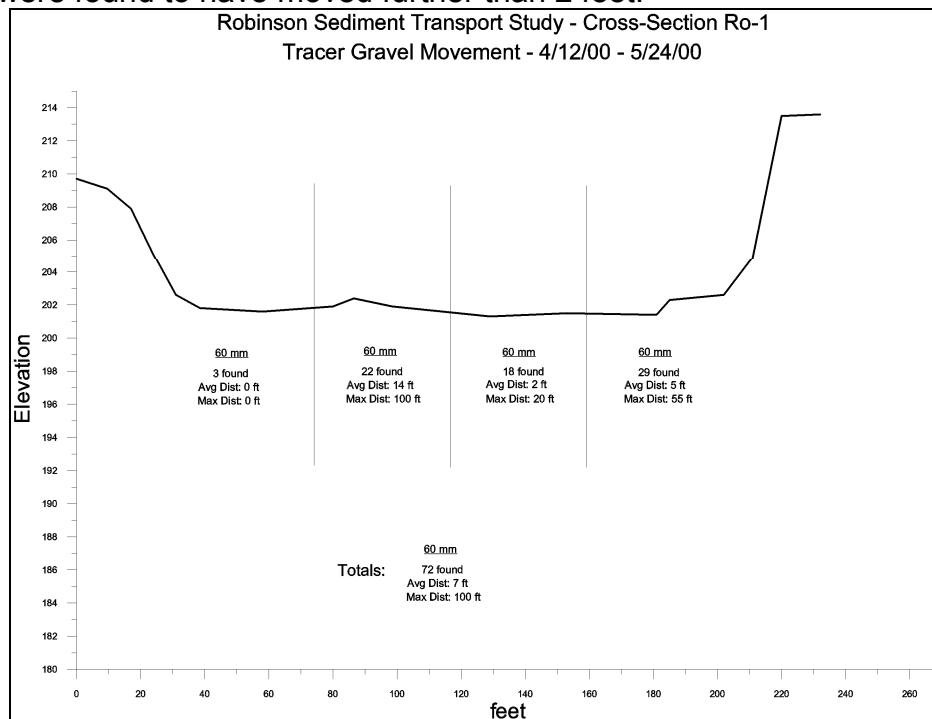


Figure 15 – May Results, Section RO-1

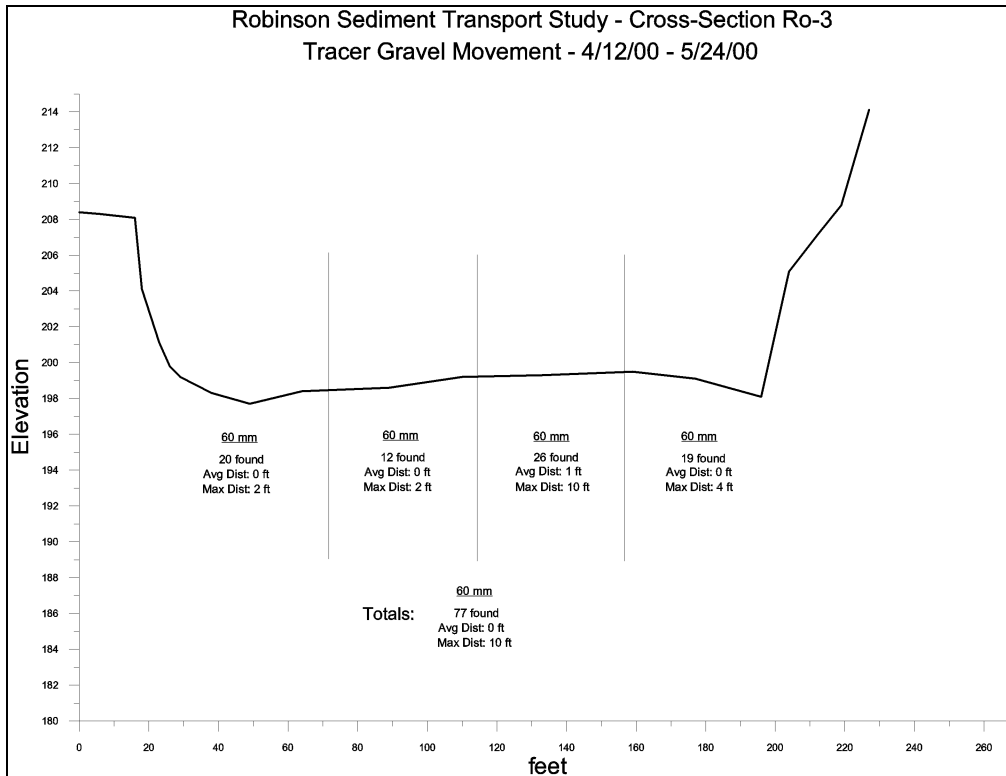
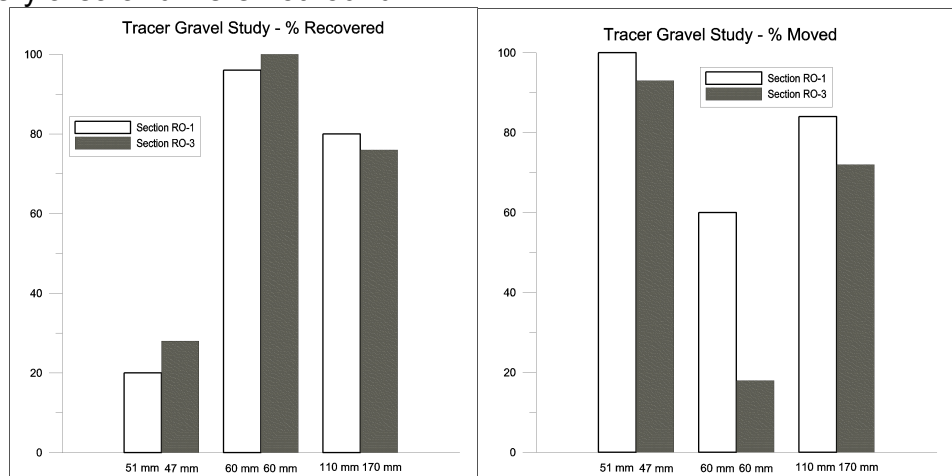


Figure 16 – May Results, Section RO-3

The percentage of particles recovered at each cross-section for both experiments is shown graphically in Figure 17. Figure 18 shows the percentage of particles which showed any movement in each flow. This percentage should not be confused with the percentage shown in the last column of Table 5, which only denotes significant movement of particles (greater than 2 feet). In the cases of the smaller particles, the percentage recovered was large when the percentage moved was small, and vice-versa. When a great deal of movement occurred many of the particles moved outside the recovery area and were not found.



Figures 17 and 18 - % Recovered and % Moved

Section	Tracer Gravel Size	Expected Q (Andrews t^*_{ci})	Expected Q ($t^*_{ci}=0.02$)	Actual Q cfs	% Moved >2 ft
RO-1	110mm	6,500	2,950	3,200+	84
RO-1	51mm	5,400	1,600	3,200+	100
RO-1	60mm	5,800	2,100	2,300	33*
RO-3	170mm	8,000	4,400	3,200+	56
RO-3	47mm	7,900	1,900	3,200+	94
RO-3	60mm	8,400	3,100	2,300	6*

* - these sets were “stomped” into the bed, rather than placed on the surface

Table 5 - Tracer Gravel Results

Table 5 shows the expected and actual flows for each experiment, as well as the resulting percentage of movement. It becomes apparent that the Andrews model results in a similar flow for most of the range of particle sizes in a channel bed, implying that incipient motion is dependent on the D_{84} particle size. Using the generalized values for t^*_{ci} in calculating the expected mobilizing flow, however, results in a wider spectrum of flows which depend on the size of the particle.

Tracer Gravel Study Conclusions

The calculations to estimate the flow required to move a particle of specified size depend largely on the values for t^*_{ci} and slope. The Andrews model for estimating t^*_{ci} is specifically applicable to the movement of particles in the bed, deposited naturally. A particle placed on the surface of the bed would require a different estimate for t^*_{ci} . Generally, a value of 0.02 to 0.025 for larger particles (D_{84}) and 0.03 to 0.045 for smaller particles (smaller than D_{50}) has been shown to model this circumstance better, as in the December experiment.

In the first experiment, Section RO-1 seemed to act as predicted. The D_{84} of the existing bed material led to calculated flows similar to those that have occurred in the reach in the recent past. Our own observations in the reach support the implication that the bed was recently mobile. Eighty-four percent of the tracer gravel moved at flows of 3,200 to 3,700 cfs which is evidence that the generalized values of t^*_{ci} are more appropriate in this situation—the particles were not placed in the bed but on the surface in shallow depressions. The value for t^*_{ci} commonly used in this situation is 0.02 (Andrews 1994, p2241). An investigation of this reach indicated that at lower flows the water surface slope should increase locally. Using a slope of 0.004 and a Manning’s “n” value of 0.038 (calculated from water surface elevation surveys) the calculated

mobilizing flow was nearly 3,000 cfs. This result seems to accurately model what we saw in the December experiment.

Similarly, the D_{84} tracer rocks placed at section RO-3 also behaved more in line with predictions using 0.02 for t^*_{ci} rather than those using the Andrews model values. The mobilizing flow calculated using the Andrews model was 8,000 cfs, but using $t^*_{ci} = 0.02$ resulted in a flow of 4,400 cfs. The actual flow peaked at 3,700 cfs and there was significant movement of 56% of the tracer rocks.

During the same experiment, the smaller gravel was placed in the same way at both cross-sections. At section RO-1, 100% of the 51 mm rocks and many of the rocks were unrecoverable. Since these rocks were small (D_{36}), the generalized value for t^*_{ci} ranges from 0.03 to 0.045. The mobilizing flow would be 1,600 cfs at 0.03, and 3,000 cfs with 0.045. Since the actual flow experienced was greater than 3,200 cfs, the experiment is inconclusive about which value to use, but the Andrews model flow prediction of 5,400 cfs was obviously not the best case. At section RO-3 results were similar, with 94% movement at 3,200 to 3,700 cfs. The Andrews model prediction results in a mobilizing flow of 7,900 cfs, while the non-Andrews prediction using 0.045 is 1,900 cfs.

The April experiment was slightly different than the December experiment procedurally. The tracer gravel was stomped into the bed, which resulted in the rocks being somewhere between part of the bed and placed on the bed surface. It would follow then that the t^*_{ci} values would still be smaller than the Andrews model predicts but larger than the generalized values of 0.02 for D_{84} and 0.03 to 0.045 for smaller particles. There is no way to know to what degree the rocks were made a part of the bed.

At section RO-1, the 60 mm rocks experienced a flow of 2,300 cfs, and 33% of the rocks moved significantly (greater than 2 feet). This implies that the mobilizing flow was probably not reached. The Andrews t^*_{ci} was 0.044 which resulted in a calculated mobilizing flow of 5,800. Using $t^*_{ci} = 0.03$, a value of 2,100 cfs results. Since the true mobilizing flow is not believed to have been reached at 2,300 cfs, it stands to reason that the mobilizing flow is somewhere between 2,300 and 5,800, and the t^*_{ci} value would be between 0.03 and 0.044.

The Andrews model t^*_{ci} for section RO-3 was 0.068, which led to a predicted mobilizing flow for 60mm bed particles of 8,400 cfs. Using $t^*_{ci} = 0.045$, the predicted flow was 3,100 cfs. The 2,300 cfs experienced by the tracer rocks moved only 18% of them, 6% significantly. This would indicate the mobilizing flow was still far off from the flow

experienced. The true mobilizing flow is probably somewhere between 3,100 and 8,400 cfs for the 60mm particle.

These first two experiments have shown the importance of the method of placement of the tracer gravel to the behavior of the particles, and the method of determining t_{ci}^* in prediction of their movement. Another experiment will take place on the same cross-sections during the winter of 2000/2001 which should further refine our model. The next experiment will involve placing particles both on the bed and some nestled into the bed to show the effect of placement on mobilizing flows. The previous experiments will serve to enable us to choose sizes for the tracer gravel which should be closer to mobilization at expected flows. The results of these experiments should be valuable in helping determine the particle size distribution necessary for the channel, and whether the on-site source of material will be of adequate size. They may show that screening of some of the material is necessary before placement in the channel. The final design channel dimensions may also be affected by the outcome of these experiments, since depths and velocities are dependent on the channel geometry and affect the shear forces on the bed material.

Test Pit Sieve Analyses

On July 18, 2000, several test pits were excavated on the Robinson Project site. The purposes were both to determine the depth of aggregate and to take samples of the selected sites for later sieve analyses. The test pits were located in two gravel deposits in the project area which will provide a large portion of the fill for the project (Figure 19). Seven pits were excavated in all, three in the downstream gravel deposit site (Figure 20) and four in the upstream site (Figure 21). The pit locations were selected to best represent the gravel deposits.

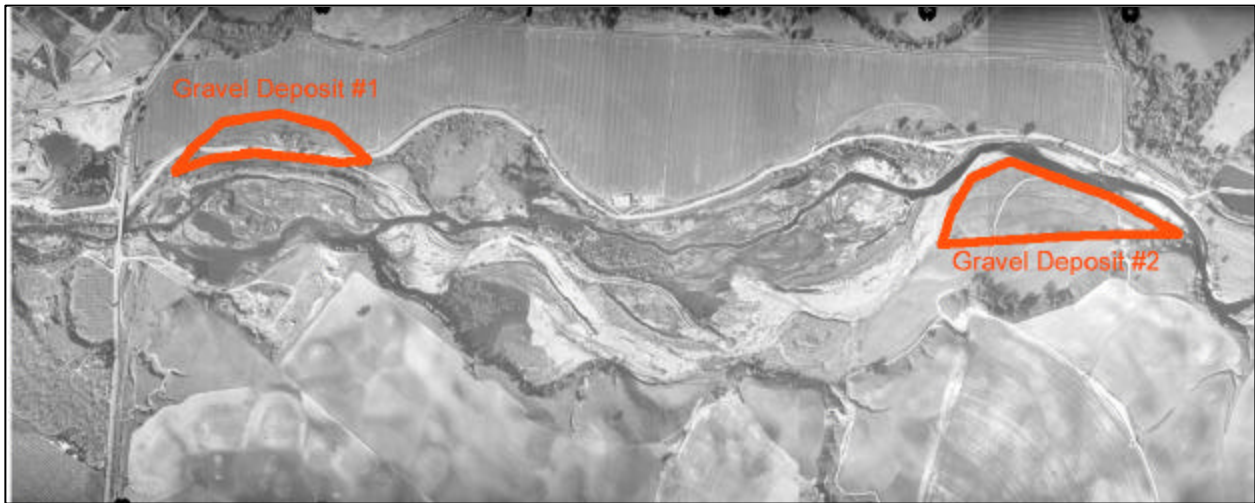


Figure 19 - Robinson Project Deposits

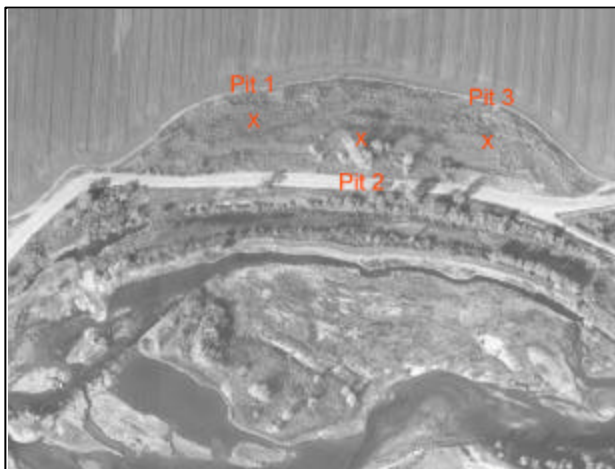


Figure 20 – Site 1

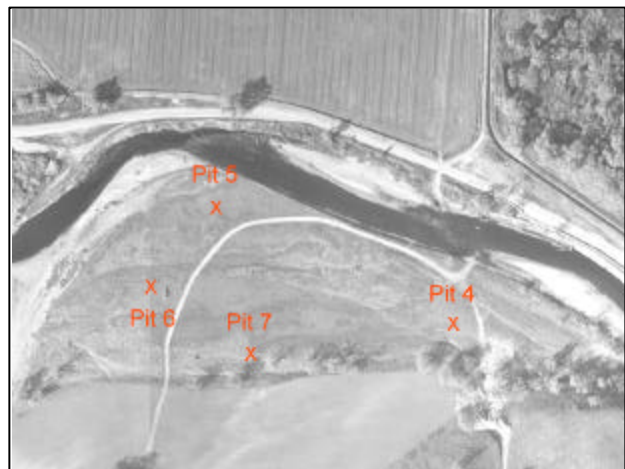


Figure 21 – Site 2

The holes were excavated by a backhoe to depths of 5 to 10 feet (Figures 22-24). Two of the sites, Pits 1 and 7, had topsoil covering the gravel deposit (Figure 24). In the sites with topsoil, the covering was two to three feet deep. Pits 1, 2, 3, 4, and 6 were

excavated to approximately 5 to 6 feet in depth and sampled at that depth. Pits 5 and 7 were excavated to between 8 and 10 feet in depth and were sampled at the approximate mid-depth point and at maximum depth.



Figure 22 - Excavation



Figure 23 – Example of Excavations



Figure 24 – Test Pit Example

Staff performed sieve analyses on samples of each of the test pits (Appendix G). The results are shown in Table 6. Also shown are average D_{50} and D_{84} for each of the two deposit sites and for all of the samples. It is probable that at least some of the excavated material will be processed for use in the new constructed channel, and one possible scenario is shown in Table 6.

	Total D ₅₀ (mm)	Total D ₈₄ (mm)	>6mm D ₅₀ (mm)	>6mm D ₈₄ (mm)
Pit 1	15	90	51	101
Pit 2	18	47	28	55
Pit 3	11	55	22	72
Pit 4	28	72	40	83
Pit 5	23	66	38	75
Pit 6	21	60	34	70
Pit 7	20	73	51	85
Site 1	16	60	33	79
Site 2	23	67	38	79
Overall	20	63	37	79

Table 6 - Sieve Analysis Results

Table 7 shows a variety of scenarios for processing the excavated material. The D₅₀, D₈₄, and percentage of total weight are shown for 4 inch and smaller, 0.5 inch and greater, 0.5 to 4 inch, and 0.25 to 4 inch.

	Site 1	Site 2
D₅₀, 4 inch and smaller	21mm	12mm
D₈₄, 4 inch and smaller	60mm	50mm
% weight, 4 inch and smaller	95.6%	94.4%
D₅₀, ½ inch and greater	35mm	32mm
D₈₄, ½ inch and greater	83mm	89mm
% weight, ½ inch and greater	59.4%	50.1%
D₅₀, ½ to 4 inch	42mm	39mm
D₈₄, ½ to 4 inch	73mm	69mm
% weight, ½ to 4 inch	55.1%	44.5%
D₅₀, ¼ to 4 inch	36mm	31mm
D₈₄, ¼ to 4 inch	71mm	62mm
% weight, ¼ to 4 inch	65.1%	55.1%

Table 7 - D₅₀, D₈₄, and Percent of Processed Material

HEC-RAS Model

DWR staff designed the channel using the equations and methods outlined in the Project Design Parameters section. We decided to then confirm the function of the design using the U.S. Corps of Engineers' Hydrologic Engineering Center River Analysis System (HEC-RAS) modeling program. Staff obtained the geometric properties for the model by using BOSS International's BOSS RMS for AutoCAD to create model cross-sections and then editing them with the design cross-section geometries. Sixty-one cross-sections, each about 200 feet apart on average, were generated for the project area using this method (See plan view, Appendix H). We estimated Manning's "n" values based both on our experience in modeling this river and on calculations made in some reaches. Values ranged from 0.032 for the channel to 0.04 to 0.05 for the floodplain. We estimated the floodplain "n" values for near-future vegetation expectations (post-revegetation).

The modeled flows were chosen by their importance in the design. The lowest flow, 225 cfs, was the anticipated spawning flow in the Merced River. We chose the design bankfull flow, 1,700 cfs, since the design calls for the river to spill out on the floodplains when flows exceed it. Finally, we chose to model the highest flow anticipated to occur in this reach, 8,000 cfs.

Two models were actually created: the design with the Highway 59 bridge as it exists, and the same design with the bridge opening 100 feet wider. At 8,000 cfs the two models showed identical water surface elevations above section 185 (sta 101+55), but below this point the existing bridge model showed a slightly higher elevation (See tables in Appendix H). Shears and velocities in the channel were slightly higher in the widened bridge model in this range, probably as a result of reduced ponding effects. Because of the lower water surface at the bridge, there is a higher energy grade slope which results in higher velocities and shears.

Since the bridge has not been widened yet, we decided to discuss the existing bridge model in this report because it can be looked at as a "worst case" situation. Appendix H contains plots of the cross-sections used in this model. The plots show the cross-sectional geometry, but also show the n-values used and resultant water surface elevations for the three model runs. At 1,700 cfs, the model shows the water surface to be within 0.2 ft of the top of the banks (bankfull) for nearly all sections, with the only place with a greater than 0.4 ft divergence being at section 513 (23+40) and 515 (22+50). At 8,000 cfs, the model shows a floodplain water depth of about 1.6 to 2.6 feet for most of the project, and depths as high as 3.3 feet at the constricted ends. The average floodplain depth at this flow is about 2.0 feet.

Channel shears at 1,700 and 8,000 cfs are shown in the tables in Appendix H, and channel and overbank shears can be seen graphically in the Figures 25 and 26. Stationing in the figures is along the design channel rather than according to the HEC-RAS station. The figures also show the calculated τ_{84} for the expected fill material (see page 35). As shown in Figure 25, the model's calculated channel shear at 1,700 cfs approaches, and in some cases exceeds, the necessary shear for mobility in the riffles. This implies that the design channel will be adequate to mobilize the bed at the design bankfull flow. Upstream of station 54+00 (the transition point from higher slope to a lower slope), the shear forces will be significantly larger which could cause some aggradation downstream. This could eventually lead to migration of the meander. It is important to note that meander migration is part of a naturally functioning stream, and is not considered a failure, but this area will likely be one focus of future adaptive management and monitoring activities for the project.

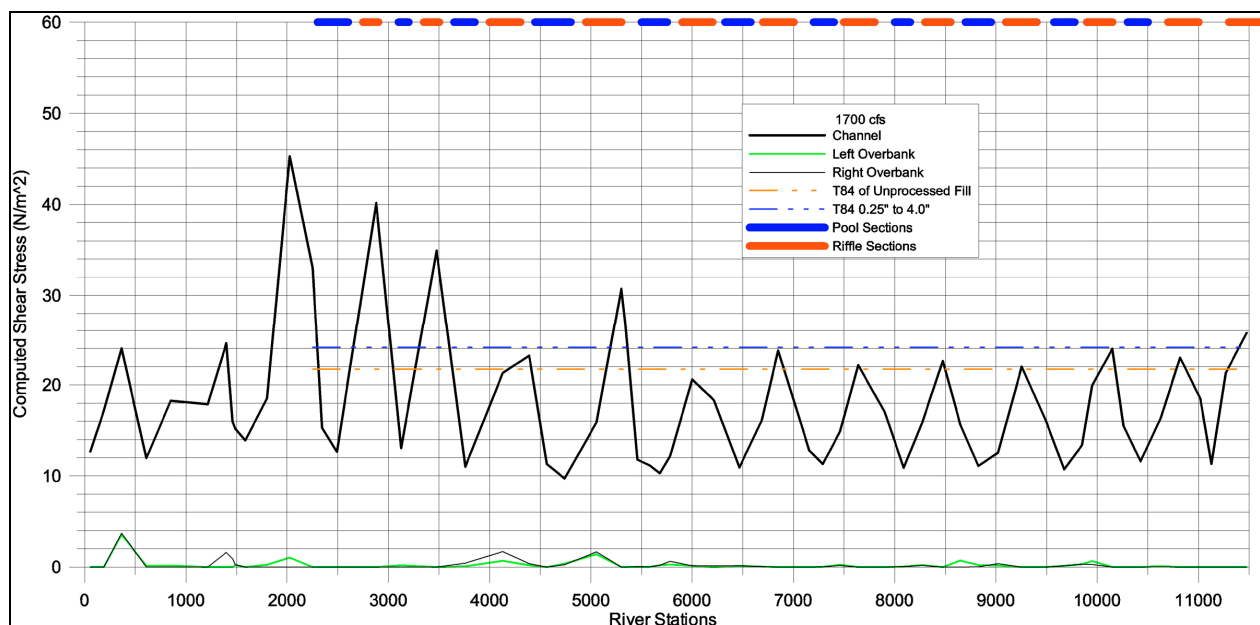


Figure 25 – Computed Shears at 1,700 cfs

Figure 26 shows the shear values at 8,000 cfs. The channel shear pattern is quite different than it is at 1,700 cfs. It is much more dependent on floodplain characteristics since they dictate the overall velocity of the flow. At very high flows the channel is likely to evolve through deposition and scour in the lower half of the project (sta 55+00 to 112+00). The model shows high channel shear values in the upstream reach, which indicates a high degree of scour. From station 0+00 to 23+00 this should not be a significant problem, since the existing channel has sustained this level of flow before. There would likely be significant scour from 23+00 to 45+00 at flood flows however, and this entire reach will be an important gravel replenishment site for the entire project. Another area of probable scour at high flows is also the narrowest reach upstream of the bridge. Between stations 90+00 and 100+00 the floodplain narrows and shears

increase in the channel. This may become another important gravel augmentation site. Overbank shears (shear forces on the floodplains) are also shown in the figure. Forces do not exceed the mobilizing force necessary throughout the project, but from stations 6+00 to 35+00 forces will approach that value. While mobilization of the floodplain particles is unlikely, the upstream reach will be monitored for such an event.

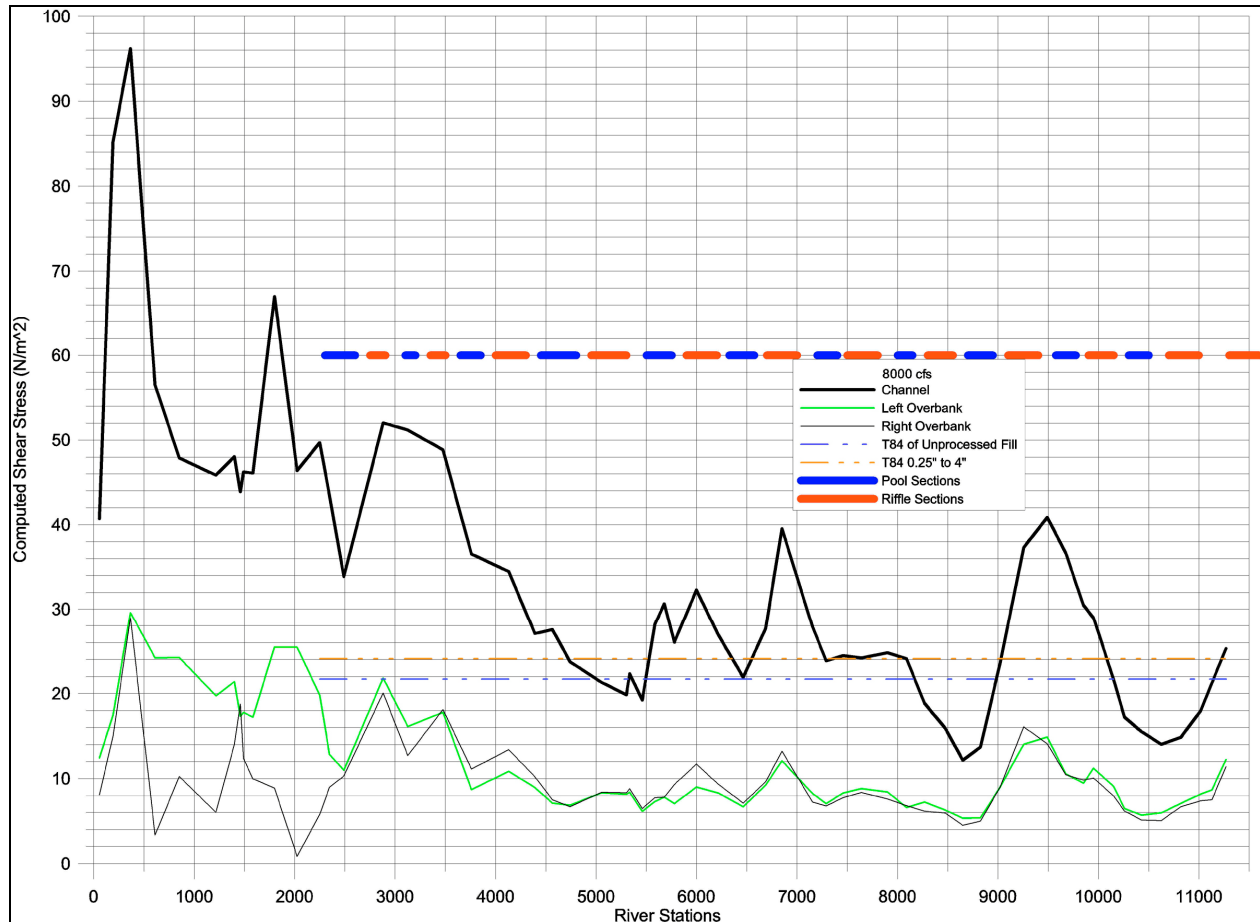


Figure 26 – Computed Shears at 8,000 cfs

Gravel Transport Rate: Stillwater Sciences Model

Stillwater Sciences has developed a model (EASI) for estimating gravel transport rates in river channels at various flows. In February 2001, Stillwater staff applied the EASI model to the MRSHEP Phase III project design based on information and parameters DWR provided. The model was applied to all three of the reaches of the project that include design channel construction (the upstream reach will not have a reshaped channel). The results of the model show that significantly higher rates of gravel transport will occur between stations 23+00 and 35+00. It estimates that the overall rate at that reach, based on current flow frequencies, is about 20,000 tons per year, or 20 times the rate of the downstream reach. The next reach downstream will have a transport rate of about 5,800 tons per year, and the lowest reach will transport about 1,000 tons per year (Table 8). This verifies the conclusions reached from the HEC-RAS model—upstream reaches will have significantly higher sediment transport rates and will play an important part in gravel replenishment efforts.

Reach	Channel Slope	Gravel Transport Rate (ton/yr)
Sta 23+00 to 35+00	0.0029	20,110
Sta 35+00 to 54+00	0.0023	5,810
Sta 54+00 to 116+00	0.0017	1,050

Table 8 – Gravel Transport Rate Summary (Courtesy of Stillwater Sciences)

Based on these data, we will likely need to try to minimize the degradation of the upstream reach, while minimizing aggradation in the downstream reach. This goal may be achieved by careful monitoring and the use of an adaptive management approach. By stabilizing the upstream reach (See Overexcavation Section) and keeping the gravel augmentation volumes to a level at which the downstream reaches can cope, these potential problems can be dealt with.

Based on the Stillwater model, we will most likely start with an augmentation volume of between 2,000 and 6,000 tons depending on flows. If more gravel is placed than can be transported by the lowest reach, some aggradation and channel migration may occur. While channel migration is not essentially negative, the effect should be minimized since the design channel will contain the best quality material, and therefore, should support the best habitat quality.

Channel Overexcavation and Material Replacement

It becomes clear, based on results from the HEC-RAS and Stillwater models and on other information presented in this report, that the size and makeup of the channel material is important to the success of the design. Because the design channel will run through several reaches of low quality materials, there is a need for some manipulation of them. We intend to “overexcavate” the channel area, meaning that rather than just cutting to finish grade, we will excavate the channel area to below grade so that more suitable material can surround the channel (see Figure 27). This “overexcavation” will be necessary for much of the length of the channel between stations 23+00 and 116+00; however, we expect to encounter areas of suitable gravel deposits along the channel alignment which will not need replacement.

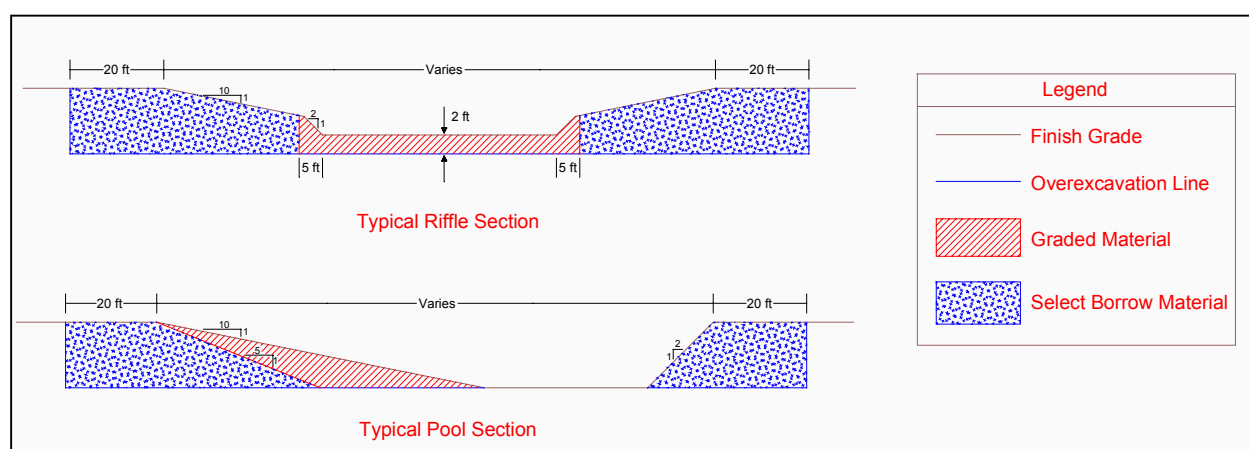


Figure 27 – Channel Overexcavation and Material Replacement

This channel excavation and material replacement is necessary for several reasons. First, the existing material is inadequate in some cases and needs to be improved so that the potential for release of fines into the river will be reduced and so that the possibility of salmon spawning in the reach will be improved. Second, by replacing the inadequate materials with materials that were originally graded by the river, we are allowing the channel some migration room. Natural channels migrate over time, and this consideration will help ensure that this channel will be able to adjust without leaving the gravel base. It also means that we will not have need of any bank protection or structures to confine the channel to the design location. In addition, as the channel migrates, the placed material will be recruited by the river to form point bars and riffles—a sign of a healthy river. The third reason for the channel “overexcavation” is that sediment mobility is very important to a stream’s ability to function. By replacing the existing materials with materials that are mobile at target flows, we will enable the stream to function within the current flow regime. The existing material is low in gravel content in some areas, so the replacement of this material with both graded and select borrow materials will ensure adequate mobility throughout the project reach.

The characteristics of the replacement materials are based on both the mobility and the makeup of the existing borrow material sites. The material which will be placed in riffles and point bars must come close to meeting mobility requirements as determined in the HEC-RAS model described above and in sediment transport modeling of the reach created by Stillwater Sciences. The borrow sites were tested (Test Pit Analyses Section) and a size distribution was developed based on the results of the analyses and on the mobility models. The “select borrow” materials that will be placed in the overexcavation area, while not ideal for mobility in the design channel, contain gravel which will suit channel migration. The river’s natural process of grading and moving gravel, coupled with planned gravel infusion of graded material, should result in a healthy stream channel.

During construction, we will grade material from the abandoned floodplains by screening the top and bottom end of the gradation curve off. This means that in the process of creating the graded material to be used in the channel, we will produce a significant amount of large cobble. In the high mobility reach between sections 23+00 and 35+00 (See HEC-RAS and Stillwater sections), we could have problems of degradation and incision of the channel if the graded material were used. In this reach, we plan to stabilize the substrate by placing the large cobbles created in the grading process below channel grade. This, along with using no graded material in the reach, should help control degradation in high flows.

Monitoring Plan

Monitoring of this project will be for both morphological and biological processes. The morphological components of the project will be monitored by the Department of Water Resources, and the draft plan is outlined here. Biological monitoring plans can be found in the Revegetation section (Appendix I), Fish Monitoring section (Appendix J), and Habitat Monitoring section (Appendix K). The Revegetation and Fish Monitoring plans can also be found in Appendices D and F of the Initial Study/Environmental Assessment document (March, 2001). The draft revegetation plan presented in Appendix I is updated and revised from the one presented in the IS/EA document.

Our morphological monitoring program will focus on looking at both the project as a whole and specific areas of concern. While the monitoring activities will produce a picture of the performance of the project design overall, several areas will be watched for changes that may occur according to our models. One area that will be monitored closely is the upstream reach floodplains. Movement of particles in the floodplain between stations 4+00 and 35+00 is predicted by the HEC-RAS model at high flows which could result in braided or split channel development. Another concern is channel and floodplain degradation between stations 4+00 and 35+00. The HEC-RAS and Stillwater Sciences models both show high gravel transport rates in this reach. This could also lead to aggradation at the slope breaks at stations 35+00 and 54+00. Another area of high transport is around station 92+00 where the narrowest part of the floodplain is. The channel will be monitored at that point to track any degradation. One more area of concern is around the Highway 59 Bridge. Backwater effects at high flows may decrease sediment transportability of the channel and aggradation may occur; however, the scheduled widening of the bridge opening should help alleviate this.

Section	Channel Survey	Floodplain Survey	Pebble Count	Tracer Gravel Study
14+00	X	X	X	
20+00	X	X		
28+00	X		X	
34+00	X			X
42+00	X		X	
48+00	X	X		
50+00	X			
54+00	X	X		
60+00	X		X	X
68+00	X	X		
76+00	X		X	
84+00	X			
92+00	X		X	X
100+00	X			
108+00	X	X		
114+00	X		X	

Table 9 - **Monitoring Cross-Sections**

The monitoring plan includes several cross-sections at which tracer gravel experiments and pebble counts will be located (Table 9, Figures 28, 29). Staff will survey those

sections and the thalweg profile immediately after construction to establish a baseline. Thereafter, we will survey the sections and profile annually if a flow of greater than 1,700 cfs has occurred, or if movement of tracer gravel has been observed; however, if three consecutive years have not yielded these conditions, we will survey the sections

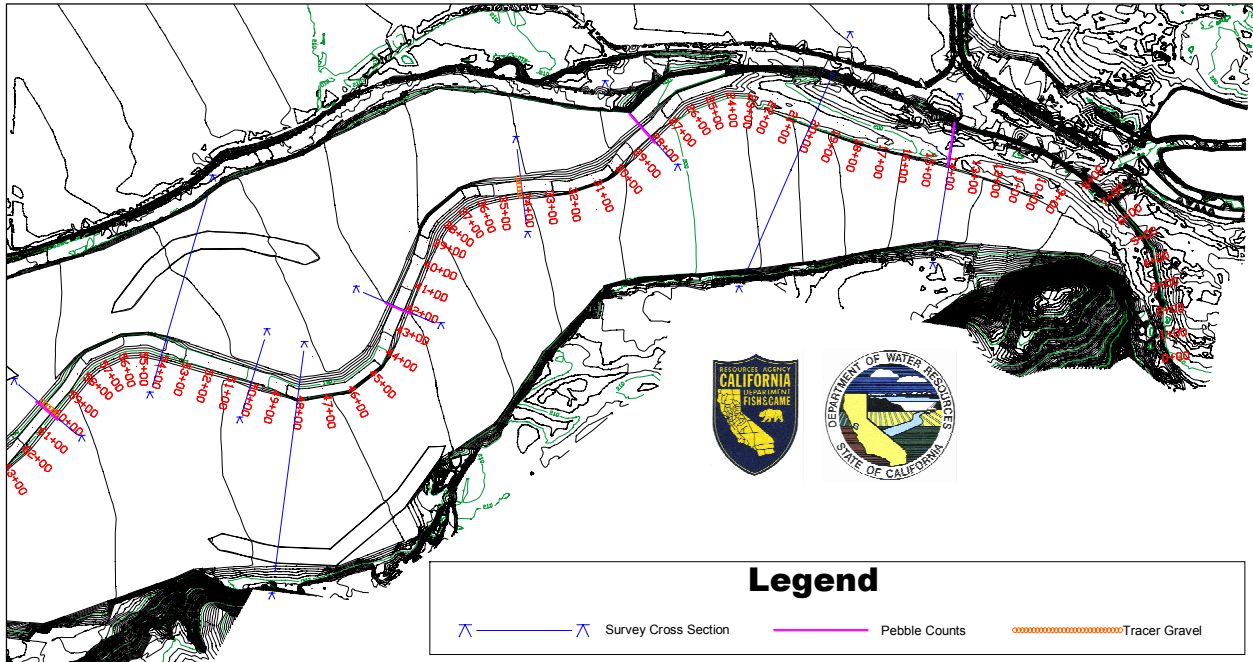


Figure 28 – Monitoring Plan, Upstream

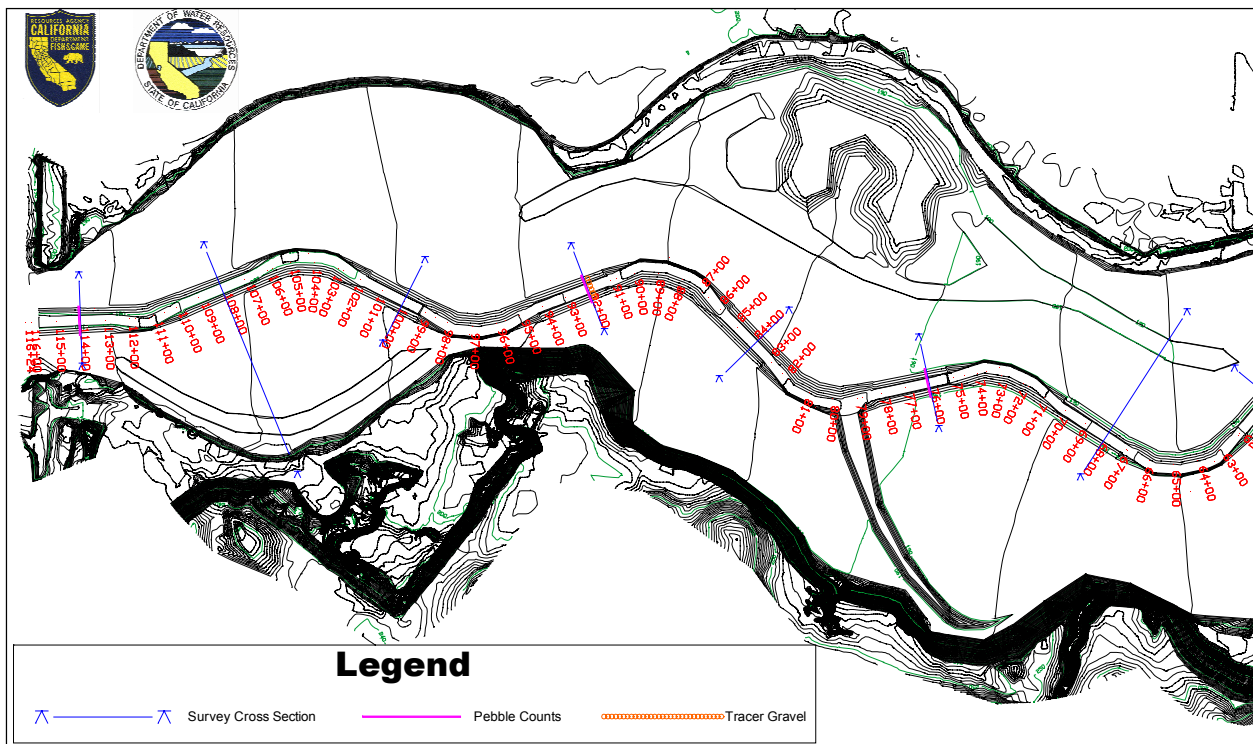


Figure 29 – Monitoring Plan, Downstream

anyway. We chose 1,700 cfs because it is the design bankfull flow, and bed movement is expected based on the models. We will also use water surface surveys at known flows to check the HEC-RAS model results. Cross-sections and profiles will be used to document any changes in the storage of alluvium. In addition to the section surveys, a coincident pebble count will help document any changes in substrate and gravel quality. Sixteen cross-sections will be regularly surveyed—seven of which are designated for the pebble counts.

Four of the monitoring cross-sections will be surveyed across the floodplain on one side (see Figure 28, 29) if flows have exceeded 3,000 cfs to monitor the SACs, and two more surveyed at the upstream end when flows exceed 5,000 cfs. The upstream monitoring sections will be used to watch for movement on the floodplain since higher flows were shown in the HEC-RAS model to have high shear in that reach. The model also showed a drop in shear at the transition around station 54+00, so we will use one cross section to monitor for aggradation at high flows at that point. This data as well as future monitoring data will be included in a future monitoring report.

These monitoring actions, and others to be determined as the project progresses, will allow engineers to assess the effectiveness of the design with respect to the project goals. They will also provide information which will assist in adaptive management decisions, and in determining volume and location of gravel replenishment projects for the reach in the future. We expect to have the replenishment sites at the upstream end where gravel transport rates should be highest, but we will use our monitoring data to confirm the specific sites.

Cooperators

The Merced River Salmon Habitat Enhancement Project is a joint project between the California Department of Water Resources and the California Department of Fish and Game in cooperation with:

- California Department of Transportation
- Delta Pumping Plant Fish Protection Agreement Committee
- Anadromous Fish Restoration Program (Central Valley Project Improvement Act)
- CALFED Bay-Delta Program
- Merced River Technical Advisory Committee
- Robinson Cattle Company

And Assistance From:

- Stillwater Sciences
- McBain and Trush

Funding

- Delta Pumping Plant Fish Protection (Four Pumps) Agreement
- U.S. Fish and Wildlife Service / Anadromous Fish Restoration Program
- U.S. Fish and Wildlife Service / CALFED Bay-Delta Program
- California Department of Fish and Game / Proposition 70 Funds
- California Department of Fish and Game, U.S. Bureau of Reclamation / Tracy Fish Facility Direct Loss Mitigation Agreement

Implementation

- California Department of Water Resources
- California Department of Fish and Game

Conclusion

The removal of the ponds from the main channel will garner several benefits. By filling them, the warmwater salmon-predator habitat will be removed, and river function will be improved. Removal of the ponds will also improve the migratory pathway and rearing and spawning habitat for salmon, and enhance the riparian corridor and river floodplain. The active river channel will be reconfigured to take better advantage of the existing flow regime and restore the ability of the river to remove fine material, recruit spawning gravel, and reduce degradation of the channel. In addition, the creation of functional floodplains will increase the stability of the channel throughout this reach. The final stages of the project include the revegetation (Appendix I) of the floodplains to enhance a riparian corridor. Gravel infusion sites will be utilized to add coarse sediment to the reach as needed after high flow events.

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Appendix A
Project Area Photo